FA-TR-76002

FEASIBILITY STUDY ON A MULTI-COMPONENT PROPELLANT SYSTEM FOR 30 MM AMMUNITION

November 1973

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U.S. ARMY ARMAMENT COMMAND

Munitions Development and Engineering Directorate

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER FA-TR-76002	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FEASIBILITY STUDY ON A MULTI-COMPONENT PROPELLANT SYSTEM FOR 30 MM AMMUNITION		5. TYPE OF REPORT & PERIOD COVERED Final Engineering Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Earl Van Artsdalen (COTR) James Dooley, Olin Corp.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS OLIN CORPORATION EAST ALTON, IL 62024		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DAAA25-73-C-0439
11. CONTROLLING OFFICE NAME AND ADDRESS FRANKFORD ARSENAL ATTN: SARFA-MDC-A PHILADELPHIA, PA 19137		12. REPORT DATE November 1973
		13. NUMBER OF PAGES 138
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Propellant Charge
Consolidated Propellant
Compacted Propellant
Increased Loading Density
Pelletized Propellant
Automatic Cannon Ammunition
30 MM Cartridge

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Using the 30 mm WECOM with a 3400 grain projectile as a test vehicle, a study was made to determine the feasibility of employing a novel propellant concept to attain maximum projectile velocity within the constraints of a 40,000 to 50,000 psi chamber pressure range. The propellant system considered, referred to as the MAGNUM Concept, consisted of a blend of BALL POWDERS in granular and pelleted form. This combination of granular and compacted propellants readily permitted a 20% increase in propellant charge weight.

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20. ABSTRACT (Cont)

To obtain maximum performance improvement from the increase in propellant charge weight, the pelleted component was surface coated with a polymer to delay ignition and initial forward movement of the projectile was facilitated by providing a free run section in the gun chamber. The net effect of these two modifications was to reduce peak chamber pressure and extend the propellant burn time thereby increasing the piezometric efficiency of the system.

The MAGNUM Concept was investigated both experimentally by computer simulation. The latter analysis was made to permit interpretation and extension of the experimental work. The effect of such variables as total charge weight, granular to pelleted propellant ratio, inhibitor coating level and length of free run were established and found to be in general agreement with the computer analysis of the system.

Although only limited efforts were directed toward propellant optimization, velocities of 2700 fps were achieved at the 40,000 psi level with a propellant charge of 775 grains, and velocities of 2800-2930 fps were obtained at the 50,000 psi level with charges of 775-970 grains. Thus, the concept was demonstrated to be a practical means of increasing projectile velocity at a given pressure level.

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ABSTRACT

Using the 30mm WECOM with a 3400 grain projectile as a test vehicle, a study was made to determine the feasibility of employing a novel propellant concept to attain maximum projectile velocity within the constraints of a 40,000 to 50,000 psi chamber pressure range. The propellant system considered, referred to as the MAGNUM Concept, consisted of a blend of BALL POWDERS in granular and pelleted form. This combination of granular and compacted propellants readily permitted a 20% increase in propellant charge weight.

To obtain maximum performance improvement from the increase in propellant charge weight, the pelleted component was surface coated with a polymer to delay ignition and initial forward movement of the projectile was facilitated by providing a free run section in the gun chamber. The net effect of these two modifications was to reduce peak chamber pressure and extend the propellant burn time thereby increasing the piezometric efficiency of the system.

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WORK STATEMENT

During the course of the feasibility study, the contractor will provide services and materials for development and test of a novel BALL propellant system for the WECOM 30mm round. The effort will meet requirements set down in the following technical scope of work:

1) Interior ballistics calculations will be made to serve as guidelines for facets of the experimental program as required to study the propellant charge design/ignition sequence/barrel design relationship.

2) A mixed granular and molded BALL propellant system will be investigated with the objective of determining the maximum velocity obtainable with prescribed combinations of projectile weight and pressure level.

3) Ballistic tests will be made in a 52 inch free-run barrel with projectile weights of 3400 and 3800 grains to optimize velocities at peak pressures of 30,000 and 40,000 psi.* Effort will be directed toward meeting an action time requirement of 2.5 msec maximum average at ambient temperature and 4.0 msec maximum individual at -65°F.

4) The contractor will provide explicit details on the method of loading any final test quantities of ammunition with specific reference to the conditions necessary to provide

*This task was subsequently modified by deletion of the 3800 grain projectile study and by extension of the pressure peak to 50,000 psi.

ballistic uniformity. In the final report, the contractor will also provide comments on and recommendations for the production loading of the designed propellant charge and feasibility of maintaining a reasonable degree of ballistic uniformity in production.

5) In order to achieve these specifications and goals, limited studies will be made of the ignition system design to match it with propellant charge functioning characteristics.

INTRODUCTION

The objective of this study was to demonstrate the feasibility of obtaining increased projectile muzzle velocity in a given system without increasing peak chamber pressure or changing cartridge configuration. The cartridge selected for the study was the 30mm WECOM employing a 3400 grain projectile. The approach taken was to utilize a dual propellant system to increase loading density. Olin refers to this variation of a high loading density propellant as its MAGNUM Concept.

MAGNUM propellant charges may be designed in two forms. In one, identified as MAGNUM ALPHA, the propellant charge consists simply of compacted pellets of Ball Propellant having a density of approximately 1.40 gm/cc surrounded by conventional granular Ball Propellant. The combination, as illustrated in Figure 1, results in an average packing density, dependent upon the ratio of the two charges, of approximately 1.20 gm/cc. This represents a 20 to 25% increase over the .95-1.00 gm/cc packing density obtained with granular propellant alone.

It will be immediately recognized that this increase in loading density in a given round must be accompanied by a propellant burn rate modification in order that the round will still function within the defined pressure limit. Experience has shown that this mixed charge functions in a manner very similar to that of an equivalent weight of granular propellant and that the total propellant charge may thus be tailored for the ballistic requirements in essentially the same manner as that employed for granular propellants.

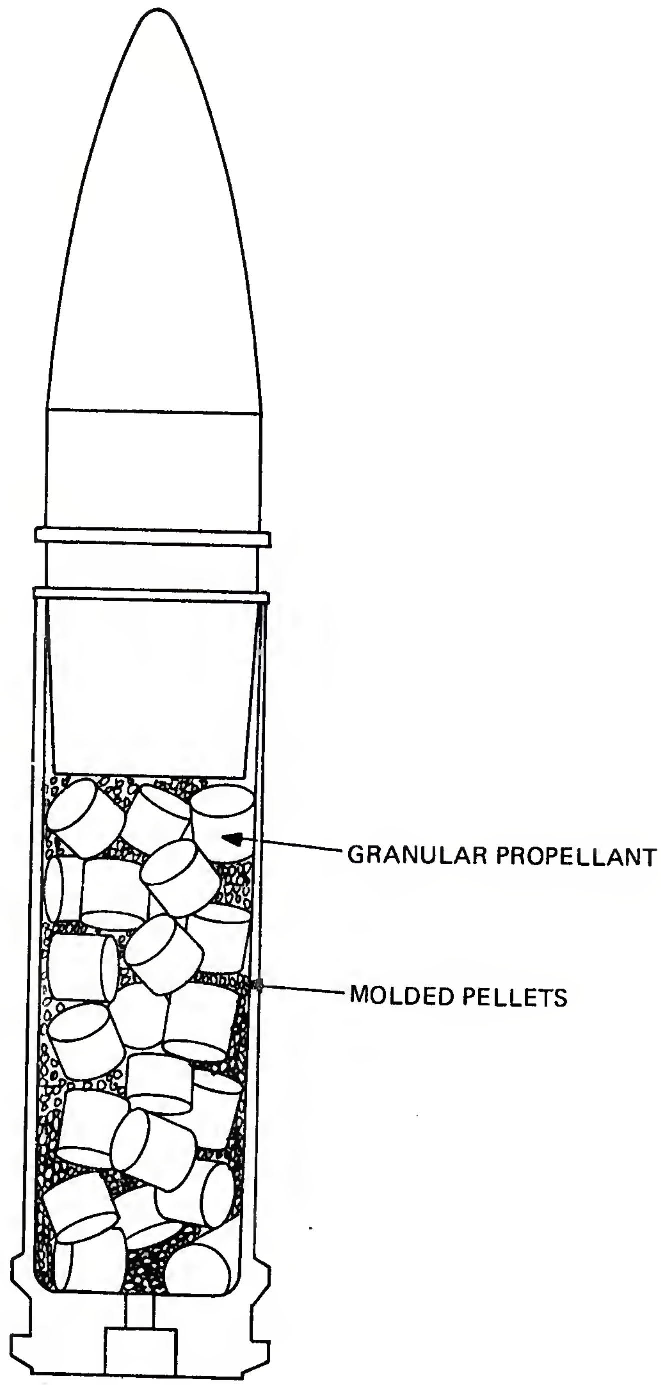


Figure 1. Magnum Concept - 30mm WECOM

The second system, identified as MAGNUM BRAVO, consists of the same mixed granular and pelleted propellant charge but employs an inhibitor coating on the surface of the pellets to effect a delay in the ignition of this portion of the propellant thereby extending the total burn period. As a further refinement, a more rapid chamber expansion rate and resulting reduced chamber pressure is obtained by employing a free-run section in the chamber. The net result is a system which provides more efficient utilization of the increased propellant energy potential.

The sequence of actions in the MAGNUM BRAVO system is as follows:

The granular propellant is ignited as in a conventional cartridge and the projectile begins its forward movement after the pressure of the combustion gases is sufficient to overcome case crimp resistance. But, unlike a conventional gun system, the rotating band engraving force resistance is not immediately encountered and initial projectile acceleration and rapid chamber volume expansion is thereby facilitated. Ignition of the propellant pellets then occurs either before or after the projectile rotating band engages the rifling of the barrel, depending on the length of the free-run section and the pelleted propellant ignition delay.

While the principle of the action may be simply described, it is obvious that the system introduces new complexities insofar as optimization is concerned. It accordingly has been the prime objective of the present work to reduce the MAGNUM BRAVO concept

to practice in such a way as to demonstrate that the action actually is as described, and that significant improvements in velocity can be achieved in this manner.

In the report that follows, the novel actions thus described are considered in some theoretical detail, the practical aspects of charge preparation and loading are discussed, and the achievements of the test firings under the experimental program are reviewed. For brevity, the general term MAGNUM is used throughout this report to describe the delayed pellet ignition - free run system unless otherwise noted.

INTERIOR BALLISTIC CALCULATIONS

The first step in consideration of the MAGNUM propellant concept for a given system is an estimation of the level of ballistic performance improvement which might be expected. Such a determination is of value both in predicting whether or not there is real merit in the concept and in assessing just how close the actual experimental work has come to meeting theoretical performance limits.

The 30mm WECOM system as defined herein was evaluated by two separate mathematical techniques. The first of these considered simply the thermochemical properties of the propellant and the physical characteristics of the weapon system to derive a velocity representing 100% propellant efficiency. The method followed is termed by Olin as an MVEL calculation and is discussed in detail in Appendix A.

Table I illustrates the effects to be expected from a given propellant operating at 100% efficiency, first when the charge weight is varied with all other factors held constant, and secondly when the maximum pressure is varied and all other elements are held constant. However, it is recognized that no propellant operates at 100% efficiency in actual practice. Experience gained with similar ammunition-gun systems shows that an MVEL efficiency of approximately 91% is the maximum that can usually be obtained. We have, therefore, also shown in Table I the velocity values for a 91% MVEL efficiency level as an illustration of realistic velocity levels which may be expected.

TABLE I

MAXIMUM THEORETICAL VELOCITY (MVEL) CALCULATIONS

Propellant Composition
11% Nitroglycerine
5% Dibutylphthalate
4% Miscellaneous
80% Nitrocellulose

Maximum Pressure (psi)	Chargeweight (grains)	MVEL (fps)	Velocity (fps) at 91% MVEL
A. Effect of Chargeweight Variation			
40,000	650	2815	2562
40,000	700	2894	2634
40,000	750	2968	2701
40,000	800	3037	2764
50,000	650	2889	2629
50,000	700	2974	2706
50,000	750	3054	2779
50,000	800	3129	2847
B. Effect of Pressure Limit Variation			
30,000	650	2711	2467
40,000	650	2815	2562
50,000	650	2889	2629
60,000	650	2944	2679
30,000	800	2907	2645
40,000	800	3037	2764
50,000	800	3129	2847
60,000	800	3199	2911

In using this data, it should be noted that the calculation in no way defines the design details of the system, i.e. it does not concern itself with the physical description of the propellant, only its average chemical composition. Nor does it include such weapon design factors as bore resistance or free run in the barrel. These latter factors are the specific subject of more detailed interior ballistic calculations which are discussed in Appendix B. The theoretical computations presented therein include consideration of the propellant grain size, shape and composition (particularly deterrent level and location); projectile bore friction; free run length and the effect of the delay period between ignition of the granular propellant and ignition of the compacted propellant pellets.

Inasmuch as the analysis is fairly lengthy and its interpretation somewhat sophisticated, no attempt will be made to summarize the work at this point. However, reference should be made to Appendix B for a proper understanding of the MAGNUM concept as use will be made of this theoretical data in interpertation of the experimental results. It should be borne in mind when reviewing this material that the theoretical analysis is far from complete and is not intended to offer an optimized design, but has been developed merely to support a proper understanding of the critical factors in the application of the MAGNUM system. In order to

assist in this, the total data available from the computations has been simplified somewhat with potentially useful factors such as unburned propellant and projectile movement given only illustrative representation.

There is sufficient correlation between the calculated and experimental data to indicate that the basic assumptions of the analytical program are generally sound. Obviously, a number of factors should be explored in greater detail in any continuing program but, in summary, the experimental results indicate that the MAGNUM Concept does perform with programmed ignition delay as postulated by the calculations and that the MVEL efficiency levels of the better propellant systems tested, while not optimized, are of a high level.

EXPERIMENTAL

A. Propellant Selection and Preparation

The multi-component propellant system used in the MAGNUM Concept required the selection of propellants for the granular and pelleted components. Inasmuch as emphasis was to be upon demonstration of the system and not upon absolute optimization of the ballistic performance, the propellants selected for the program were standard BALL POWDERS or simple variations of these involving only the omission of one or more steps in the processing of conventional Ball Propellants. The various propellants discussed in this report are listed in Table II together with their nominal physical and chemical characteristics.

Propellants molded into pellet form varied slightly from normal granular propellants in that the graphite coating was reduced to less than 0.05%. Initially some powders were surface coated with less than 1% potassium salt and tin dioxide to improve their handling properties in pelleting but this did not prove to be necessary and was omitted from the bulk of the studies in order to simplify the overall process.

Pelleting was accomplished on a standard Stokes B-2 rotary multi-station pelleting press using a free flowing solvent-propellant premix. The pellets were then dried to reduce residual solvent content to an acceptable level. Preliminary studies were made to determine the effect of pellet density on

TABLE II

PROPELLANT CHEMICAL AND PHYSICAL CHARACTERISTICS

Propellant	Average Grain Diameter	Web	Nitro-glycerine	Deterrent
WC 870	.0315"	Sphere	10.0%	6.5%
Rolled WC 870	.0315"	.019"	11.5%	8.0%
WC 760	.0225"	.016"	10.0%	6.0%
400 BALL	.0225"	Sphere	10.0%	5.0%
WC 749	.0225"	.015"	10.0%	5.25%
WC 740	.0225"	.014"	10.0%	5.0%
WC 844	.0225"	.014"	10.0%	5.0%
WC 680	.0145"	.011"	10.0%	3.75%
.013"/.009" BALL	.0110"	Sphere	10.0%	2.5%
Undeterred	.0200"	.014"	10.0%	0 %
Undeterred(.010")	.0200"	.011"	10.0%	0 %

Propellants are listed in order of approximate relative quickness from the "slowest," WC 870, to the "fastest" propellant, Undeterred (.010").

pellet strength and inhibitor coating uniformity. Based on these studies a minimum density of 1.4 gm/cc was selected, a density which was near the upper limit which could be achieved with a compacted propellant, but one which could be produced without difficulty.

Initially two sizes of pellets were prepared in right cylinder form, one 0.25" long x 0.35" diameter and the other 0.10" x 0.10". There was no significant difference in total packing density between the two pellet sizes, but the smaller pellets offered more surface area per unit weight and hence would require a higher level of inhibitor coating. Therefore, the large pellet size was selected for the remainder of the study. No specific studies were undertaken to optimize pellet size and shape.

Perhaps the most critical factor in the finishing of the pellets for the MAGNUM System is the application of a controlled uniform inhibitor coating. Previous Olin development work on 25mm and 27mm caseless cartridges had shown an acrylic polymer, Acryloid B-66 manufactured by Rohn and Haas to be a satisfactory inhibitor and it was, therefore, initially selected for this study. This particular polymer has the desirable properties of being soluble in toluene, a non-solvent for nitrocellulose and other constituents of BALL POWDER, and of having a rapid solvent release thus simplifying removal of the solvent after the coating has been applied.

There is no reason to expect it to be unique with respect to its ignition delay properties; it was simply selected because of the properties of the liquid form of the polymer. Its use has continued because of its effectiveness.

Acryloid B-66 does possess one disadvantage in that it has a brief period of surface tackiness during the period of solvent removal. For this reason, consideration was given to the use of an alternate material, Polywax 655 manufactured by the Bareco Division of the Petrolite Corporation. However, this material proved to form a laminar discontinuous film and the alternate inhibitor studies were discontinued as being outside the main thrust of the present program.

To be an effective ignition retardant, the inhibitor coating must obviously have good physical characteristics and adhere well to the surface of the pelleted propellant. However, since it is a negative energy material, it is desirable to minimize the quantity used. For this reason, two methods of applying the inhibitor coating were investigated during the course of this program, spray and dip coating.

For spray coating, the pellets were placed in a small heated (60°-70°C) tumbling barrel and the inhibitor solution applied using a freon-powered sprayer. Tumbling of the pellets was continued for an additional 10-15 minutes after completion of spray coating to decrease the solvent level. The pellets

were then dried overnight in an oven at 60°C to remove the balance of the solvent. Inhibitor levels of 0.5% to 1.5% by weight were achieved by this method.

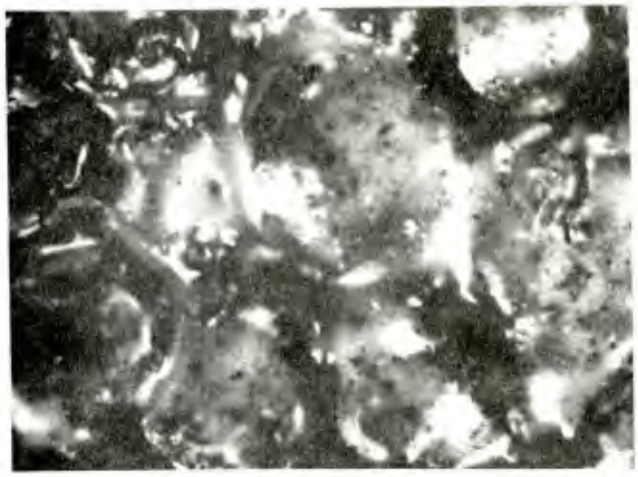
For dip coating, the pellets, held in a wire mesh basket, were dipped into the liquid-polymer solution; removed and shaken to remove droplets; transferred to an absorbent material and drained of solution. They were then replaced in the tray and vibrated while drying to a nontacky finish. As in the case with the sprayed pellets, they were then dried overnight at 60°C in an oven to remove the balance of the solvent. This process provided inhibitor levels of 2.0% to 3.6% by weight resulting in an inhibitor film thickness of .0016" to .0020".

One potential problem with the dipped pellets was that of penetration beyond the surface of the grain. Some pellets, particularly those formed from rolled powders, contained cracks between the surface grains which were ready-made paths for coating material to penetrate the pellet. In order to prevent this penetration, a 2.5% solid nitrocellulose lacquer sealer was applied prior to dip coating in the polymer solution. This sealer was also applied by dip coating in a manner similar to that described above for the inhibitor. By filling in the cracks and voids at the surface of the pellet, the nitrocellulose lacquer provided a continuous surface for inhibitor application without significant effect upon the overall energy level of the propellant. Note must be made that this sealer coat was not

necessary on all pellets; those formulated from spherical powder grains, particularly of smaller diameter, possessed a natural continuous skin after pressing and drying.

Figures 2 and 3 illustrate typical spray and dip coatings. Although continuous coatings such as those illustrated in these photographs were consistently obtained after process techniques were established, coatings such as that illustrated in Figure 4 were obtained initially indicating the need for careful process control.

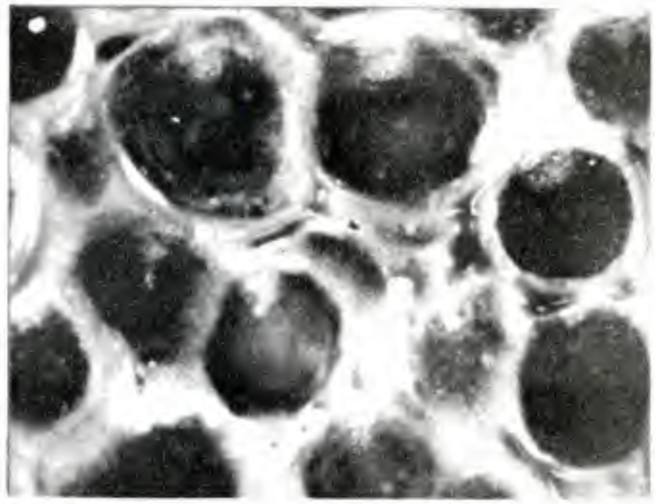
Visual observation of the pellet surface and pellet cross sections proved to be a valid means of qualitatively evaluating coating continuity. However, a more quantitative analysis was desired for selected samples and direct analysis for the acrylate presented a problem in a laboratory not specifically equipped for this test. As an aid for a quick quantitative determination, 5% by weight of finely divided tin dioxide was added to the inhibitor solution. With the acrylic solution thus "tagged", it was a simple matter to conduct a quantitative analysis for tin dioxide on the coated and uncoated pellets and thereby calculate the amount of the acrylic coating. Maintenance of a uniform dispersion of a heavy material such as tin dioxide presents some difficulties and this procedure is therefore recognized as only an interim procedure, but one which was well suited for this study.



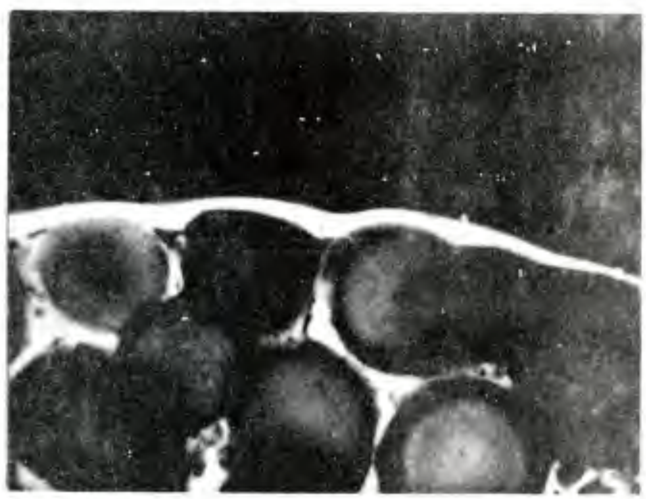
SURFACE OF SPRAYED PELLET

CROSS SECTION OF SPRAYED PELLET

Figure 2. Spray Coated Pellets with Continuous Film



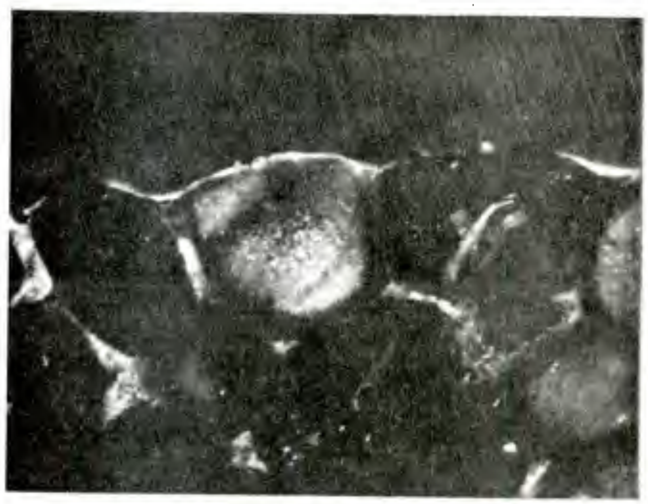
SURFACE OF DIPPED PELLET



CROSS SECTION OF DIPPED PELLET

Figure 3. Dipped Coated Pellets

SURFACE OF SPRAYED PELLET



CROSS SECTION OF SPRAYED PELLET

Figure 4. Spray Coated Pellets with Discontinuous Film

During the course of the experimental program, it was determined that pellets dip coated with a single layer of polymer applied from a 20% solids solution had ignition delay characteristics in the desired range and no further coating process studies were required for the present study. However, it should be noted that higher inhibitor coating levels, if required, would be feasible thru modification of the acrylic solids concentration of the solution or by multiple dips.

B. Propellant Loading

For the experimental program it was necessary to identify the maximum practical propellant loading density and to establish a procedure which would insure uniformity of weights and propellant placement. The procedure employed may be described as follows:

Twenty grains of the granular propellant were first loaded into the case to insure that a portion of the granular propellant was in close proximity to the primer flash hole. The weighed pelleted charge was next loaded and settled into position by vibration while being held under a slight pressure by a plunger fitting inside the case mouth and resting on the top of the pellets. The remainder of the weighed granular propellant charge was then added. This amount of total propellant did not overflow the case but was at a level in excess of that required for projectile seating. Again the propellant was settled into position in the interstices between the pellets by vibration while being subjected to a slight downward pressure from a plunger resting against the powder surface. Vibration continued until the plunger indicated that the propellant was settled to the required level for projectile loading. For the bulk of the experimental work a standard laboratory test tube vibrator was used to settle the propellant.

In carrying out the loading process, care must be taken to insure: (1) that the pelleted propellant fraction is settled below the level required for projectile seating, and (2) that the granular powder is settled throughout the pelleted grains so that no air voids remain.

As would be expected, the difficulty in loading was directly related to the ratio of pelleted to granular propellant as well as the total charge weight. Although it is desirable from a ballistic performance standpoint to load the maximum possible charge weight, it is necessary from a practical production standpoint to load a charge weight slightly below this level. Taking both of these factors into consideration, it was found that the most satisfactory propellant load consisted of 300 grains of granular propellant and 475 grains of pelleted propellant. This represents a total charge weight increase of 20% as compared with typical granular propellant loads.

During the experimental program, it was frequently necessary to test less than full case propellant loads. In rounds thus loaded with reduced propellant charges, cotton wadding was inserted to occupy the free air space and to assure that the propellant remained under some restraint to prevent segregation during handling.

C. Limitations on the Experimental Program

Before proceeding to a discussion of the experimental studies, several general comments are in order. The original scope of work specified a study of the MAGNUM propellant system in the standard 30mm WECOM cartridge using 3400 and 3800 grain projectiles. Prior to the start of the program, the requirement for the 3800 grain projectile study was deleted. The original program also specified that the study would be directed toward obtaining maximum velocity at the 30,000 and 40,000 psi chamber pressure levels. However, during a mid-program conference at Frankford Arsenal, we were directed to increase the maximum pressure level to 50,000 psi and to de-emphasize development of a propellant for the 30,000 psi level. The studies reported herein reflect these changes in program direction.

The original test program was based on the firing of approximately 2000 rounds of ammunition. As work progressed, it became apparent that this number of projectiles could not be made available and eventually only slightly more than 600 projectiles were supplied, some of which required weight modification prior to use. This component shortage was compounded by the fact that the test barrels initially supplied did not meet the bore finish specification and as a result bore frictions were of such a high order as to invalidate much of the experimental work conducted with it. New barrels

were supplied, but by the time the problem was recognized, 142 rounds of only limited experimental value had been fired. No analysis of the ballistic data resulting from the firing of these rounds is included in the following discussion, but the firings are listed in the shot record contained in Appendix C.

Because of these various changes and problems, the total level of experimental firing was greatly reduced from that which was originally scheduled. This resulted in elimination of proposed work with an improved ignition system and a greatly diminished program of replication firing. Instead, the experimental work was primarily directed toward assessing of the general nature of the MAGNUM propellant action and in identification of the critical system parameters. Emphasis was placed upon the definition of propellants, the effects of free-run variations, and demonstration that the calculated increases in velocity were practical to achieve. The ballistic tests, while limited in quantity, are greatly enhanced in value by reference to the theoretical analysis presented in Appendix B.

D. Performance Summary

The general experimental approach followed during this program was to evaluate a series of propellant design variations with a given free-run condition and then to increase the free run and repeat the study under the new conditions. Granular propellant firings were made for baseline reference. Similarly, uncoated propellant pellets were fired in combination with granular propellant to establish the effect of consolidation alone. In neither of these cases was a formal effort made to optimize ballistic performance. However, during the course of these firings, quite efficient performance levels resulted, thus increasing the value of the comparison between conditions.

The bulk of the study concentrated on firings with inhibitor coated pellets in order to determine the effect of various propellant combinations and to determine the level of inhibitor coating required for satisfactory ignition delay. Work initially started with a barrel with one-half inch free run and continued with one, two and three inch free-run conditions. During the course of the study, it was found that the initial propellants selected could be substantially improved upon and work was continued in another barrel starting with the zero free-run condition and progressing to the one and two inch free-run levels.

An overview of the program results is shown in Table III and Figure 5. A complete tabulation of test firings is given in Appendix C. It should be noted that all pressure measurements are uncorrected piezoelectric readings and that all velocity measurements were recorded at a distance of 25 feet from the muzzle.

The results demonstrate that it is possible to achieve significantly higher velocity levels within the specified pressure limits by the use of the MAGNUM approach. With the standard 30mm WECOM cartridge with a 3400 grain projectile, a velocity of 2800 fps was obtained at the 50,000 psi chamber pressure limit and a velocity of approximately 2700 fps was obtained at the 40,000 psi pressure limit. These values agree closely with maximum realistic performance levels determined by interior ballistic calculations. With increased case volume and corresponding increased propellant charge weight resulting from the use of a modified 3400 grain projectile, a velocity of approximately 2930 fps was obtained at the 50,000 psi chamber pressure level. Propellant optimization could be expected to result in even further performance improvements.

TABLE III

PERFORMANCE SUMMARY

Granular Propellant Type	Granular Propellant Chg. Wt. (grains)	Pelleted Propellant Type	Pelleted Propellant Chg. Wt. (grains)	Total Chg. Wt. (grains)	0" Free Run Pressure (psi)	0" Free Run Velocity (fps)	2" Free Run Pressure (psi)	2" Free Run Velocity (fps)	3" Free Run Pressure (psi)	3" Free Run Velocity (fps)
400 BALL	650	-	-	650	42,400	2525	24,200	2291		
WC844	650	-	-	650	50,100	2638	43,400	2638		
400 BALL	300	WC844 (1)	325	625	52,400	2564	43,800	2508		
400 BALL	300	WC844 (1)	375	675			46,300	2632		
400 BALL	300	WC844	450	750	59,700	2795	47,300	2728		
WC844	300	WC680	375	675	54,600	2675				
WC844	300	WC680	425	725			41,900	2695		
WC844	300	WC680	450	750			46,200	2772		
WC844	300	WC680	475	775			54,500	2858	46,700	2768
WC844/400 BALL (3)	300	WC680	475	775			47,100	2804	43,700	2750
WC844	350	WC680	530	880 (4)			49,500	2828	46,700	2846
WC844/400 BALL (2)	370	WC680	550	920 (4)			52,300	2939	49,900	2916
WC844/400 BALL (3)	395	WC680	575	970 (4)			55,100	3004	52,000	3002

(1) Pellets not inhibitor coated
(2) WC844/400 BALL in a 2/1 ratio
(3) WC844/400 BALL in a 1/2 ratio
(4) Increased case volume rounds

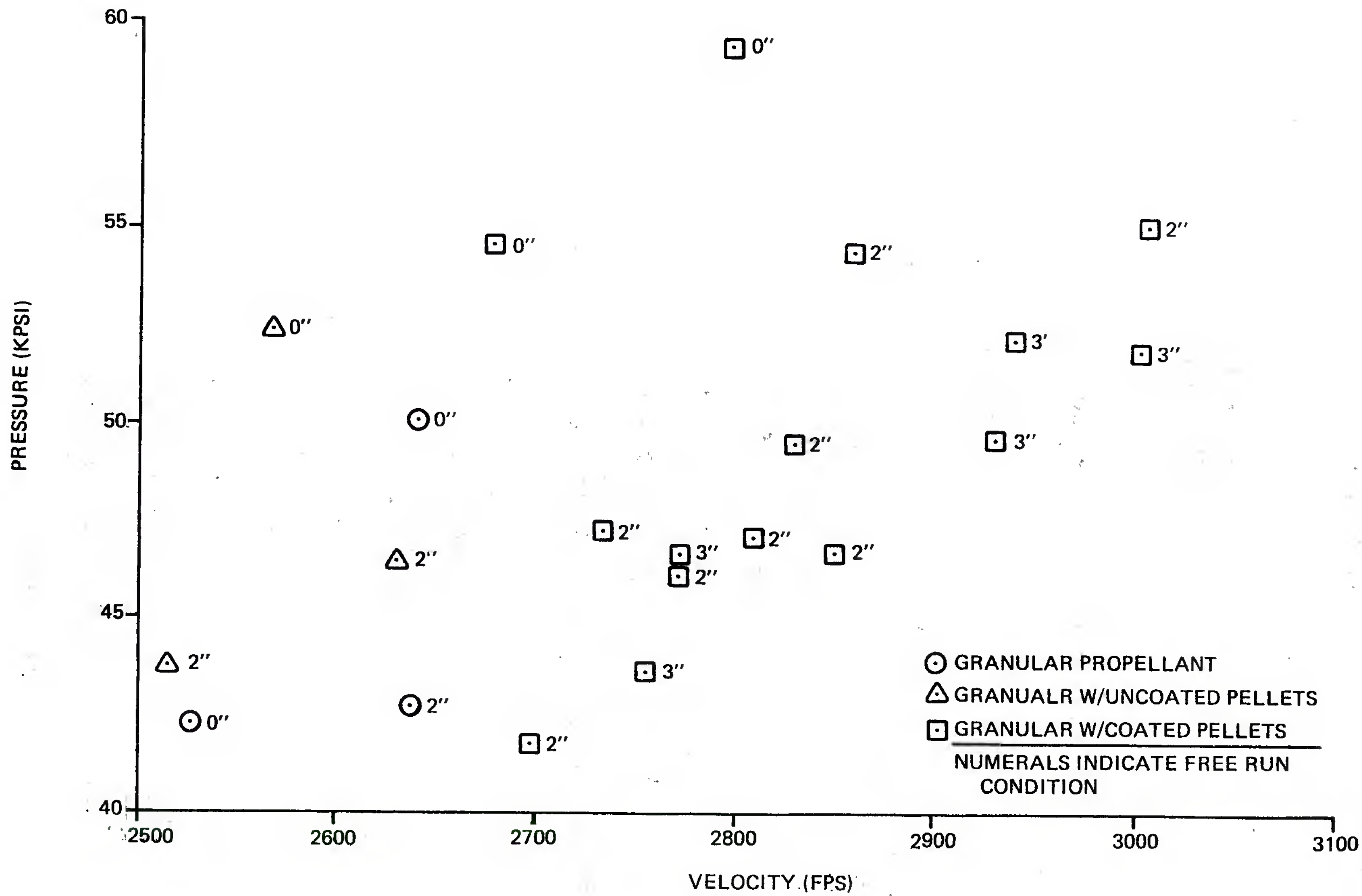


Figure 5. Performance Summary

E. Granular Propellant

A comparison of the standard WECOM 30mm System and the modified WECOM 30mm System which was specified for this study is shown below.

	Standard WECOM 30mm	Modified WECOM 30mm
Projectile Weight	3,000 grains	3,400 grains
Maximum Chamber Pressure	30,000 psi	50,000 psi
Maximum Average Action Time at 70°F	2.5 ms	2.5 ms
Maximum Individual Action Time at -65°F	4.0 ms	4.0 ms
Barrel Length	42.0 in.	52.0 in.
Case Volume	2.55 cu. in.	2.55 cu. in.

A 2,200 fps projectile velocity is specified for the standard WECOM 30mm Gun System but a reference velocity for the modified system had not been established. It was therefore necessary to establish for this study a reference against which velocity improvements could be measured.

Table IV shows the ballistic results which were obtained with full case charges of granular propellant in the 52 inch WECOM 30mm test barrel. Since experimental work on this program was limited to standard Ball Propellants and variations thereof, these three propellants provide satisfactory performance references for the MAGNUM propellants in the 40,000 to 50,000 psi chamber pressure range.

TABLE IV

GRANULAR PROPELLANT PERFORMANCE

Barrel #3, 0" Free Run
Propellant Charge Weight: 650 grains

Propellant	Shot No.	Action Time (ms)	Pressure (psi)	Velocity (fps)
WC 760	Ave. 499 & 500	2.78	35,000	2397
400 BALL	Ave. 472 & 473	3.23	42,400	2525
WC 844	Ave. 476 & 477	2.65	50,100	2638

Based on these results, the nominal maximum velocity for a full case granular propellant charge is considered, for purposes of this study, to be 2,630 fps at a chamber pressure of 50,000 psi and 2,500 fps at a 40,000 psi chamber pressure.

A limited number of tests were also conducted to determine the effect of free run on granular propellant. As shown by the following data extracted from Appendix B, Table B-5, the introduction of a free run section in the barrel would be expected to produce a significant reduction in both pressure and velocity.

Charge Weight (grains)	Propellant Type	Free Run	Pressure (psi)	Velocity (fps)
650	A15%-S21"	0"	42,599	2508
650	A15%-S21"	1"	32,759	2397
650	B15%-R14"	0"	44,669	2597
650	B15%-R14"	1"	34,521	2474

However, the experimental results, a summary of which is shown in Table V, demonstrated an insignificant effect for WC 760 and WC 844 BALL POWDERs and a greater effect than that predicted with the 400 BALL sample. The cause of this difference has not been established, but it is postulated that the 400 BALL results reflect greater projectile movement during the ignition cycle.

TABLE V

EFFECT OF FREE RUN ON GRANULAR PROPELLANTS

Propellant Charge Weight: 650 grains

Free Run	Barrel No.	Shot No.	Action Time (ms)	Pressure (psi)	Velocity (fps)
		WC 760			
0"	3	Ave. 491-493	3.00	32,000	2351
0"	3	Ave. 499&500	2.78	35,000	2397
1"	3	Ave. 526&527	2.91	34,800	2400
1"	2	Ave. 337&338	-	31,000	2378
2"	2	Ave. 346&348	3.42	30,200	2376
		400 BALL			
0"	3	Ave. 472&473	3.23	42,400	2525
1"	3	Ave. 522&524	3.33	24,200	2291
2"	3	Ave. 531-533	3.22	24,200	2322
		WC 844			
0"	3	Ave. 476&477	2.65	50,100	2638
1"	2	Ave. 269&270	-	40,200	2575
1"	2	Ave. 287-289	3.14	40,700	2603
1"	2	Ave. 324&325	-	45,500	2611
2"	2	Ave. 359-361	2.57	43,400	2595

F. Ballistic Effect of Solvent Bonding

Olin's MAGNUM ALPHA concept consists simply of a mixed granular and pelleted propellant fired in a standard gun-cartridge system. Concept feasibility therefore depends solely upon the ballistic efficiency which can be obtained with this mixed propellant charge. Correspondingly, it is readily apparent that pelleted propellant efficiency is also fundamental to the MAGNUM BRAVO concept.

Previous experimental work on caseless ammunition programs has demonstrated that a solvent bonded Ball Propellant, when properly ignited, will burn essentially as a granular propellant. This fact was again confirmed by a brief series of tests performed using a MAGNUM ALPHA propellant in the standard WECOM 30mm cartridge.

Table VI shows a comparison of the ballistic performance of granular and MAGNUM ALPHA propellants. These results indicate that the pelleted propellant portion of the mixed charge is burning essentially the same as an equivalent quantity of granular propellant although the pressure-velocity relationship is somewhat inferior to that of the granular propellants alone. The fact that the pellets are burning essentially as a granular propellant is further confirmed by Table VII wherein is shown the degree of ballistic uniformity attained in a four shot series of solvent bonded propellant charges. Although the

TABLE VI

BALLISTIC COMPARISON - GRANULAR AND SOLVENT BONDED PROPELLANTS

Barrel #3, 0" Free Run

Shot No.	Propellant	Total Chg. Wt. (grains)	Action Time (ms)	Pressure (psi)	Velocity (fps)
Average 474 & 475	Granular WC844	620	2.86	46,600	2562
Average 476 & 477	Granular WC844	650	2.65	50,100	2638
Average 472 & 473	Granular 400 BALL	650	3.23	42,400	2525
Average 501 - 504	Granular 400 BALL with Pelleted WC844	628	2.48	52,400	2564

TABLE VII

PELLETIZED PROPELLANT BALLISTIC UNIFORMITY

Barrel #3, 0" Free Run
Propellant: Granular - 400 BALL
Pelleted - WC844

Shot No.	Charge Weight (Grains) Granular	Pelleted	Total	Action Time (ms)	Pressure (psi)	Velocity (fps)
501	300	327	627	2.50	52,300	2555
502	300	328	628	2.46	52,700	2570
503	300	329	629	2.48	52,000	2567
504	300	328	628	2.47	52,500	2563
		Average	628	2.48	52,400	2564
				EV.	700	15

small number of shots is not sufficient for a firm assessment of pelleted propellant uniformity, it does indicate that a reasonable degree of uniformity may be attained.

Although the MAGNUM ALPHA concept is intended to be used with an unmodified gun barrel, additional tests were conducted to ascertain the effect of free run. As shown in Table VIII, the effect of a free run on a 400 BALL/WC 844 MAGNUM ALPHA charge is essentially identical to that obtained with granular WC 844.

It is obvious that a slower propellant combination would be required to utilize the increased quantity of propellant which can be loaded with the MAGNUM ALPHA system, but since this program was primarily directed toward demonstration of the MAGNUM BRAVO approach, no attempt was made to optimize ballistic performance with uncoated pellets. These limited tests did however serve to demonstrate that solvent bonding does represent a practical method for achieving higher propellant packing density.

TABLE VIII

EFFECT OF FREE RUN ON MAGNUM ALPHA PROPELLANTS

Propellant: Granular - 400 BALL
Pelleted - WC 844

Shot No.	Barrel No.	Free Run	Charge Weight (Grains) Granular	Pelleted	Total	Action Time (ms)	Pressure (psi)	Velocity (fps)
Ave. 501-504	3	0"	300	328	628	2.48	52,400	2564
294	2	1"	300	325	625	1.73	49,000	2550
295	2	1"	300	358	658	3.71	52,100	2621
377	2	2"	300	322	622	2.28	43,800	2508
378	2	2"	300	355	655	-	42,600	2571
379	2	2"	300	379	679	2.65	46,300	2632

G. Charge/Volume Interactions

During the course of the experimental studies both the total weight of propellant charge and the case fill level varied widely. The impact of the latter upon overall ballistic performance was investigated briefly as shown in Table IX. Here, 650 grains of WC 844 in various ratios of granular to pelleted charge were fired in a two inch free run barrel. As may be seen, the pressure and velocity levels steadily decreased as the percentage of pelleted charge increased. This may, in part, be attributed to the increase in overall "deterrent" level caused by the inhibitor coating on the pelleted portion of the charge. Total inhibitor content in the examples shown varied from 0.2% for the 66 grain pellet charge to 1.05% for the 346 grain charge resulting in an increase in total "deterrent" content from 5.2% to 6.05%.

It is also noted MVEL efficiency decreased as the pellet to granular ratio was raised. This decrease in efficiency is apparently caused by the use of a relatively slow propellant in the pellets and an excessive pellet ignition delay resulting in unburned propellant as illustrated in Appendix B, Table B-7. The quantity of unburned propellant would obviously, increase as the pelleted portion of the charge is increased resulting in the demonstrated decrease in performance. It is also possible that the reduced granular charge results in a longer pellet ignition delay which would further contribute to the quantity of unburned propellant.

TABLE IX

CONSTANT CHARGE WEIGHT STUDY

Barrel #2, 2" Free Run
Propellant: Granular - WC 844
Pelleted - WC 844 with 2.0% dip coated inhibitor

Shot No.	Charge Weight (grains) Granular	Pelleted	Total	Action Time (ms)	Pressure (psi)	Velocity (fps)	Case Fill Level
Ave. 388 & 389	585	66	651	2.52	44,100	2582	93%
Ave. 390 & 391	520	133	653	2.62	40,700	2831	90%
Ave. 392 & 393	450	199	649	2.72	36,200	2748	87%
394	385	265	650	2.87	31,800	2375	84%
395	310	346	656	2.96	31,500	2399	82%

To complete this portion of the study, a second series was run as shown in Table X wherein the charge weight was varied while the case fill volume was held constant. This caused the total charge weight to increase as the percentage of pellets in the charge increased, but pressures and velocities did not appreciably change with this increase in charge weight. Again, the lower performance level is attributed to higher inhibitor concentration and incomplete combustion of the pelleted charges.

TABLE X

CONSTANT CASE FILL VOLUME STUDY

Barrel #2, 2" Free Run
Propellant: Granular - WC 844
Pelleted - WC 844 with 2.0% dip coated inhibitor

Shot No.	Charge Weight (grains)			Action Time (ms)	Pressure (psi)	Velocity (fps)
	Granular	Pelleted	Total			
398	640	66	706	2.37	51,700	2697
399	587	139	726	2.43	50,600	2706
400	534	207	741	2.38	50,100	2680
401	484	265	749	2.47	48,400	2660
402	441	326	767	2.40	52,300	2684

H. Ballistic Control with Inhibitor Coatings

Although the increase in propellant charge weight which can be attained with pelleted propellants will, in itself, provide a higher projectile velocity, it is possible to also improve the piezometric efficiency of the propellant by delaying pellet ignition thereby lowering peak pressure and extending the burn time. The critical influence which the inhibitor coating level has on pressure and velocity is illustrated by the following computer simulation data extracted from Appendix B, Table B-7.

Granular Propellant	Pelleted Propellant	Ignition Delay (ms)	Pressure (psi)	Velocity (fps)
A15%-S12"(RQ1.7)	A15%-S18"(RQ1.2)	.4 ms	58,452	2699
A15%-S12"(RQ1.7)	A15%-S18"(RQ1.2)	.6 ms	39,182	2482
A15%-S12"(RQ1.7)	A15%-S18"(RQ1.2)	.8 ms	33,603	2209
A15%-S12"(RQ1.7)	A15%-S15"(RQ1.4)	.4 ms	65,830	2786
A15%-S12"(RQ1.7)	A15%-S15"(RQ1.4)	.6 ms	40,804	2585
A15%-S12"(RQ1.7)	A15%-S15"(RQ1.4)	.8 ms	33,603	2321
A15%-S12"(RQ1.7)	B15%-R8" (RQ2.0)	.5 ms	63,326	2787
A15%-S12"(RQ1.7)	B15%-R8" (RQ2.0)	.6 ms	43,891	2692
A15%-S12"(RQ1.7)	B15%-R8" (RQ2.0)	.65 ms	38,252	2637

Based on previous development work, the use of an acrylic lacquer coating on the pellet surface was selected as the most practical method for inhibiting pellet ignition. Since it was recognized that the inhibitor coating also reduces the overall energy potential of the propellant system, initial tests were conducted with relatively low levels of inhibitor applied by

spray coating. As illustrated by the ballistic test data contained in Table XI, spray coatings resulted in a significant improvement in the pressure-velocity relationship as compared with uncoated pellets and the best pressure-velocity relationships are obtained at the higher coating levels. It was also noted that further improvement in the pressure-velocity relationship could be obtained using a free run barrel with these propellants as illustrated in Table XII.

Since a one percent coating was the maximum practical level which could be applied under laboratory conditions, emphasis shifted to evaluation of dip coated pellets. The longer ignition delay which could be obtained with these heavier coatings permitted evaluation of faster pellet propellants which computer simulation indicated would provide better ballistic performance. A summary of these initial evaluations is shown in Table XIII.

Various combinations of propellants and dip coating levels were tested with some performance improvement noted, but it was apparent that variations in inhibitor coating levels were to a large degree obscuring the effects of pelleted propellant burn rate changes. During these tests, promising performance was obtained with a 1.9% dip coated WC 680 pellet lot. Accordingly, primary emphasis was placed on optimizing ballistic performance with this coated pellet lot during the remainder of the program.

TABLE XI

BALLISTIC PERFORMANCE OF SPRAY COATED PELLETS

Barrel #2
Propellant: Granular - 400 BALL
Pelleted - WC 844

Shot No.	Free Run	Charge Weight (grains) Granular	Pelleted	Total	Coating Level And Method	Pressure (psi)	Velocity (fps)
183	½"	300	350	650	Uncoated	79,700	2643
Ave. 185 & 186	½"	300	446	746	0.55% Spray	54,100	2763
Ave. 204 & 205	½"	300	448	748	0.60% Spray	58,700	2830
Ave. 211 & 212	½"	300	451	751	1.05% Spray	53,300	2799
296	1"	300	377	677	Uncoated	58,800	2669
Ave. 242 - 244	1"	300	452	752	1.00% Spray	54,100	2676
Ave. 260 & 261	1"	300	454	754	1.05% Spray	51,200	2732
Ave. 248 & 249	1"	300	454	754	1.19% Spray	49,200	2671

TABLE XII

BALLISTIC PERFORMANCE OF SPRAY COATED PELLETS

Propellant: Granular - 400 BALL
Pelleted - WC 844 with 1.00% spray coated inhibitor

Shot No.	Barrel No.	Free Run	Charge Weight (grains) Granular	Pelleted	Total	Pressure (psi	Velocity (fps)
Ave. 505-507	3	0"	300	451	751	59,700	2795
Ave. 227-229	2	½"	300	452	752	52,400	2740
Ave. 242-244	2	1"	300	452	752	54,100	2676
Ave. 356-358	2	2"	300	453	753	47,300	2728

TABLE XIII

BALLISTIC PERFORMANCE OF DIP COATED PELLETS

Barrel #2

Shot No.	Free Run	Charge Weight (grains) Granular	Pelleted	Total	Propellant Type Granular	Pelleted	Inhibitor Coating Description	Pressure (psi)	Velocity (fps)
Ave. 256&257	1"	300	425	725	400 BALL	WC 844 w/10% Undeterred	2% Dip*	51,600	2665
Ave. 258&259	1"	300	450	750	400 BALL	WC 844 w/10% Undeterred	2% Dip*	57,200	2763
300	1"	300	477	777	400 BALL	WC 844 w/10% Undeterred	NC,2% Dip*	29,400	2482
290	1"	340	476	816	400 BALL	WC 844 w/10% Undeterred	NC,2% Dip*	41,400	2731
Ave. 306&307	1"	340	472	812	WC 844	WC 844 w/10% Undeterred	NC,2% Dip*	51,400	2786
Ave. 308&309	1"	340	474	814	WC 844	WC 844 w/10% Undeterred(.010")	NC,2% Dip*	56,100	2800
Ave. 310&311	1"	340	471	811	WC 844	WC 844 w/25% Undeterred	NC,2% Dip*	54,000	2785
Ave. 271-273	1"	300	480	780	WC 844	WC 844	NC,3.6% Dip	38,200	2603
Ave. 326&327	1"	300	325	625	WC 870	.013"/.009"	2% Dip*	39,200	2445
314	1"	300	447	747	WC 870	.013"/.009"	2% Dip*	79,500	2859
Ave. 375&376	2"	340	476	816	WC 844	WC 844	NC,3.6% Dip	46,600	2716
Ave. 366&367	2"	300	476	776	WC 844	WC 844 w/10% Undeterred	NC,2% Dip*	43,000	2637
369	2"	300	452	752	WC 844	WC 680	1.9% Dip	46,200	2772
Ave. 370-372	2"	300	473	773	WC 844	WC 680	1.9% Dip	54,500	2858
454	2"	300	399	699	400 BALL	WC 660	2% Dip*	57,100	2689
Ave. 386&387	2"	300	477	777	400 BALL	WC 680	1.9% Dip	31,800	2602

*Approximate inhibitor level, quantitative analysis not performed.

I. Ballistic Control With Granular Propellants

Although the computer simulation program did not specifically explore the effect which the ballistic burn rate of the granular portion of the MAGNUM BRAVO propellant charge would have on the overall pressure and velocity obtained with a given pelleted propellant, an illustration of this effect can be seen in the following data extracted from Appendix B, Tables B-7, B-8 and B-10.

Propellant Charge Weight: Granular - 300 grains
Pelleted - 450 grains

Granular Propellant	Pelleted Propellant	Ignition Delay(ms)	Pressure (psi)	Velocity (fps)
A15%-R8" (RQ2.2)	B15%-R8"(RQ2.0)	.55 ms	56,002	2753
A15%-S12"(RQ1.7)	B15%-R8"(RQ2.0)	.55 ms	53,237	2742

Propellant Charge Weight: Granular - 300 grains
Pelleted - 400 grains

Granular Propellant	Pelleted Propellant	Ignition Delay(ms)	Pressure (psi)	Velocity (fps)
A15%-S12"(RQ1.7)	A15%-S15"(RQ1.4)	.40 ms	65,830	2786
A15%-S12"(RQ1.0)	A15%-S15"(RQ1.4)	.40 ms	46,163	2659

It was found experimentally that the magnitude of the change was even greater than that predicted. As demonstrated by the experimental data shown in Table XIV and Figure 6, chamber pressure could be varied from the 30,000 to 50,000 psi pressure range with relatively minor changes in the burn rate of the granular propellant with good ballistic efficiency obtained across this pressure range.

TABLE XIV

EFFECT OF GRANULAR PROPELLANT

Propellant: Granular - as noted in Table
Pelleted - WC 680 with 1.9% dip coated inhibitor

Shot No.	Charge Weight (grains) Granular	Pelleted	Total	Granular Propellant Type	Pressure (psi)	Velocity (fps)
			Barrel #2, 2" Free Run			
Ave. 386 & 387	300	477	777	400 BALL	31,800	2602
Ave. 423 & 424	300	472	772	WC844/400 BALL (1/2)	38,700	2679
Ave. 421 & 422	300	477	777	WC844/400 BALL (2/1)	45,900	2761
Ave. 370-372	300	473	773	WC844	54,500	2858
			Barrel #3, 2" Free Run			
Ave. 556-565	300	475	775	WC844/400 BALL (2/1)	47,100	2804
			Barrel #2, 3" Free Run			
465	300	471	771	WC844/400 BALL (2/1)	43,700	2750

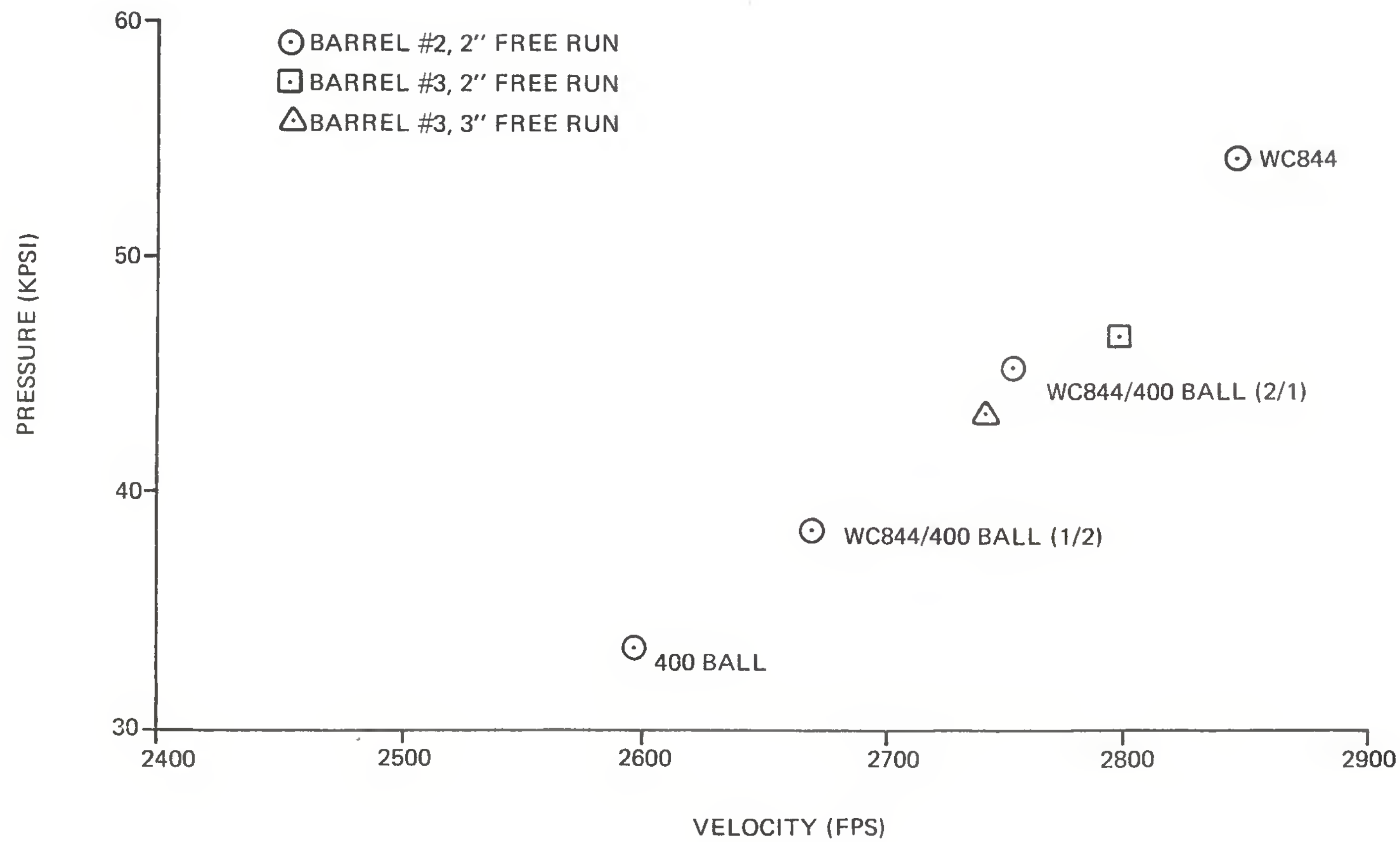


Figure 6. Effect of Granular Propellant

The reason for this large change is not fully understood and it is obvious that further exploration of this effect should be carried out both by computer simulation and through additional experimental work. Regardless of the cause, the fact that ballistic control can apparently be achieved by proper selection of the granular propellant is extremely improtant since it provides a simple means by which variations in inhibited propellant lots may be compensated.

J. Effect of Free Run

With the heavier dip coating on the pellets, ballistic tests showed good correlation with the length of free run as had been predicted by computer simulation. Experimental test data illustrating the effect of free run is presented in Table XV and a graphical plot of this data is shown in Figure 7.

For comparison purposes, computer simulation data extracted from Appendix B, Table B-13 is shown below:

Free Run	Ignition Delay	Maximum Pressure	Muzzle Velocity
0"	0.5 ms	62,711	2841
.5"	0.5 ms	46,061	2729
1"	0.5 ms	42,888	2705
2"	0.5 ms	40,663	2689
4"	0.5 ms	39,594	2681

The ballistic test data shown in Table XV indicates that for the specific combination of propellant and ignition delay tested, a 2" free run condition provides the highest velocity at any given pressure level. For this reason, a 2" free run was selected for the final experimental test series.

TABLE XV

EFFECT OF FREE RUN

Propellant: Granular - WC 844
Pelleted - WC 680 with 1.9% dip coated inhibitor

Free Run	Shot No.	Barrel No.	Charge Weight (grains) Granular	Pelleted	Total	Pressure (psi)	Velocity (fps)
0"	489	3	300	300	600	39,800	2441
0"	490	3	300	323	623	49,800	2563
0"	497	3	300	352	652	47,000	2587
0"	Ave. 513-515	3	300	376	676	54,600	2677
1"	Ave. 528-530	3	300	404	704	40,400	2596
2"	355	2	300	402	702	34,900	2579
2"	368	2	300	427	727	41,900	2695
2"	369	2	300	452	752	46,200	2772
2"	Ave. 370-372	2	300	473	773	54,500	2858
3"	464	2	300	476	776	46,700	2768

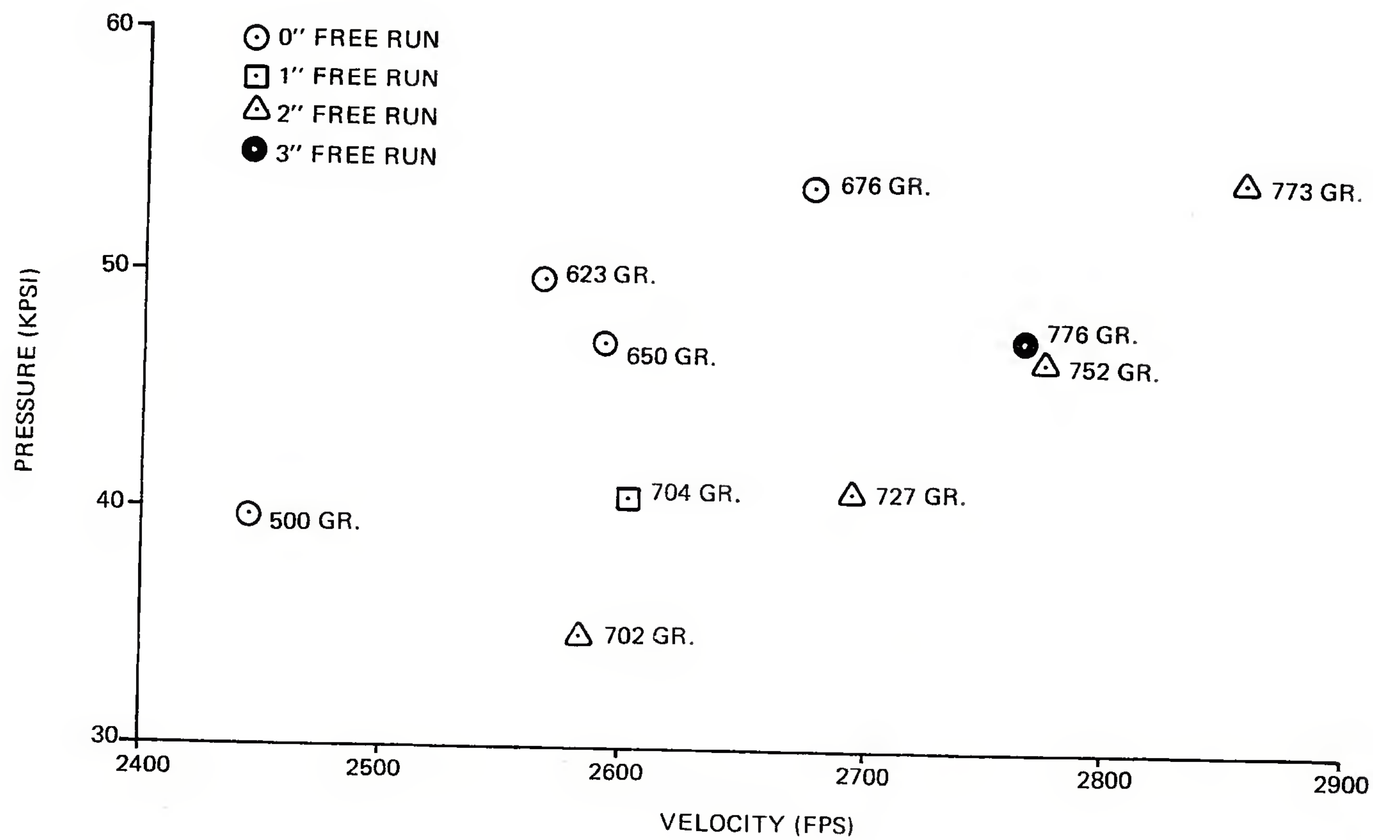


Figure 7. Effect of Free Run

K. Ballistic Uniformity and Ballistic Temperature Coefficient

To conclude the study with the standard WECOM 30mm round, the most efficient propellant system for the 50,000 psi chamber pressure level was tested at ambient, high and low temperatures, the results of which are shown in Table XVI. However, the test series proved to be of limited value in determining propellant uniformity because the projectiles remaining for this work were defective, having rotating bands which had an excessive amount of flash on the aft edge or which were slightly crooked. As indicated in Table XVI, two of the rotating bands separated from the projectiles in flight hitting down range equipment. Since detector screens were not used with this test series, other undetected separations may have also occurred.

In spite of the aforementioned projectile deficiencies, the tests served to demonstrate the existence of an unsatisfactory low temperature ignition condition. Based on the fact that none of the rounds fired gave excessive muzzle flash or evidence of unburned propellant, this low temperature deficiency is attributed to excessive delay in ignition of the granular propellant rather than excessive delay in pellet ignition. Therefore, the unsatisfactory performance is indicative of an inadequate ignition system rather than a deficiency in the MAGNUM propellant system. It is also noted

TABLE XVI

BALLISTIC UNIFORMITY AND
BALLISTIC TEMPERATURE COEFFICIENT

Barrel #3, 2" Free Run
Propellant: Granular - 300 grains WC844/400 BALL in a 2/1 ratio
Pelleted - 475 grains WC 680 with 1.9% dip coated inhibitor

Shot No.	Action Time(ms)	Pressure (psi)	Velocity (fps)
AMBIENT TEMPERATURE (77°F)			
556	-	41,700	2731
557	2.60	51,200	2861
558	2.63	50,200	2824
559	2.51	52,300	2850
560	2.80	45,300	- *
561	2.75	47,900	- *
562	2.72	46,400	2808
563	2.66	49,400	2833
564	2.84	44,100	2771
565	2.90	42,700	2752
Average	2.71	47,100	2804
EV	.39	10,600	130
SD	.12	3,660	47.4

*Rotating band separated from projectile.

Shot No.	Action Time(ms)	Pressure (psi)	Velocity (fps)
HIGH TEMPERATURE (165°F)			
566	2.71	45,700	2791
567	2.62	51,400	2846
568	2.82	48,100	2806
569	2.72	45,100	2789
570	2.75	43,600	2796
Average	2.72	46,780	2805
EV	.20	7,800	57
LOW TEMPERATURE (-65°F)			
571	3.51	21,700	2427
572	4.08	16,400	2258
573	3.21	30,800	2575
574	4.08	15,600	2229
575	5.06	10,300	1955
Average	3.99	18,960	2289
EV	1.85	20,500	620

that pressure and velocity uniformity at ambient temperature is promising but not as good as typical granular propellant performance. This too may be the result of an unsatisfactory ignition condition in addition to the aforementioned projectile deficiencies. With improved ignition, the MAGNUM charge ballistic uniformity should equal that of the granular propellant standards.

L. Propellant Ignition

It was recognized that the M36 primer igniter used in the present 30mm WECOM round is marginal in performance and that the heavier charge weight of propellant to be ignited might complicate this problem. Allowance was accordingly made in the original work plan for a separate study of an improved ignition system. However, because of the reduced number of projectiles supplied for the test program and in view of the delays caused by the previously discussed barrel problem, this work was placed on low priority and no such studies were actually conducted.

Ignition, as judged by action time, was continually monitored during the experimental test firings. A number of mechanical difficulties were encountered in this measurement, primarily related to the test fixture set-up itself and not to the use of the MAGNUM charge. In general, the action time obtained with ambient temperature test firings was in agreement with the velocity levels obtained and compared favorably with the average 2.79 millisecond action time obtained in test firing of rounds on a previous WECOM 30mm granular propellant development program. The problem thus was not immediately severe enough to require modification for this study.

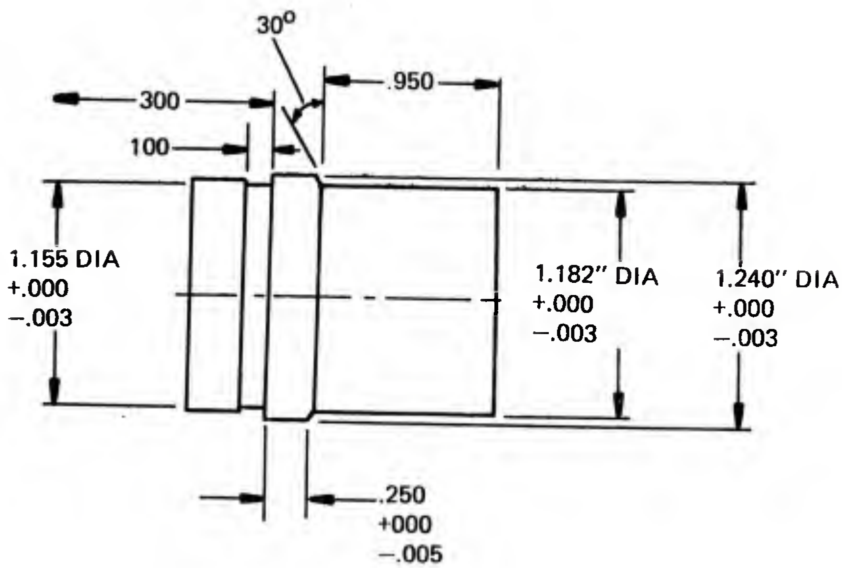
Although ignition was satisfactory for propellant evaluations at ambient temperature condition, the low temperature results show an excessive ballistic change demonstrating the necessity for investigation of ignition in any future work that may be conducted using the WECOM 30mm round. On the other hand, it must be noted that propellant ignition is highly dependent upon the specific round under investigation and that MAGNUM propellants may well prove to be completely suitable with ignition systems already in use in other rounds.

M. Studies with Increased Case Volume

This feasibility study was primarily directed toward obtaining maximum projectile velocity with a standard WECOM 30mm cartridge case and projectile. As an extension of this study, a limited number of tests were performed to determine what additional velocity improvements might be achieved by use of a modified projectile with a shorter seating depth and resulting increased case capacity.

For these tests, a number of short base 3400 grain projectiles were machined from brass bar stock in accordance with the configuration drawing shown in Figure 8. Using approximately the same two-to-three granular-to-pelleted charge weight ratio that had previously been selected, a total propellant charge of 970 grains could be loaded with this modified projectile. As expected, higher velocity levels were obtained at a given pressure level as shown in Table XVII.

Although the propellant system was not optimized for the increased case volume, it is apparent that a velocity of at least 2930 fps can be obtained with a 3400 grain projectile at a 50,000 psi chamber pressure.



SHORT BASE, 30MM WECOM PROJECTILE

MATERIAL: #360 FREE MACHINING BRASS

FINAL WEIGHT – 3400 GRAINS $^{+000}_{-10}$ GRAINS

ADJUST WEIGHT BY DRILL NOSE W/1/2" DRILL

Figure 8. Short Base, 30mm WECOM Projectile

TABLE XVII

MODIFIED PROJECTILE TESTS

Barrel #2
Propellant: Granular - As indicated
Pelleted - WC 680 with 1.9% dip coated inhibitor

Shot No.	Charge Weight (grains)			2" Free Run		3" Free Run	
	Granular	Pelleted	Total	Pressure (psi)	Velocity (fps)	Pressure (psi)	Velocity (fps)
441 & 469	350 (1)	530	880	49,500	2828	46,700	2846
446 & 470	370 (2)	550	920	52,300	2939	49,900	2916
448 & 462	395 (3)	575	970	55,100	3004	52,000	3002

(1) WC 844
(2) WC 844/400 BALL in a 2/1 ratio
(3) WC 844/400 BALL in a 1/2 ratio

PRODUCTION CONSIDERATIONS

The utilization of any novel propellant system is, in part, dependent upon the suitability of the concept for scale-up to production. For the MAGNUM propellant concept, the primary new elements involved are (1) preparation of a portion of the propellant in a consolidated pelleted form, (2) controlled inhibitor coating of these pellets and (3) loading of the total high density charge. Production considerations for each of these basic operations is discussed in this section.

Propellant Pelleting

The operations involved in the manufacture of consolidated propellant pellets are (a) selection of a suitable base powder, (b) the mixture of this with a prescribed quantity of a selected solvent, (c) the automatic feeding and pelleting of the solvent wet mix, (d) the removal of the residual solvent and possibly (e) the "deburring" of the cured pellets. It is apparent from the pilot plant process descriptions given in Section A of this report that scale-up of each of these operations is relatively straightforward requiring only standard production equipment. It should also be noted that thousands of propellant pellets were produced for this program and that over a million ignitor front supports have been produced in a similar manner for use in the 152mm consumable cartridge. Therefore, the general method of propellant pelletizing is considered to be well established.

Pellet Coating

Experience in the application of the inhibitor coating has been on a more limited, essentially laboratory, scale. No special equipment was designed for the coating operation as none was warranted by the scale of the work. Nevertheless, both general coating methods could be readily adapted to production scale equipment with the only major technical question being the proper handling of the coated pellets as they pass through the brief surface tackiness stage.

Propellant Loading

Loading of the two component propellant charge has been limited to a handload operation to date but production scale loading of MAGNUM propellants differs from standard propellant loading in only two respects. First, the propellant loading will involve more than a single step operation, i.e., the granular and the pelleted elements of the charge will require separate handling. Second, each segment of the charge will require some vibration or movement to facilitate settling into its naturally occurring firmly packed mode. During this latter operation some restraint on the total charge is advisable to avoid the possibility of segregation of the two elements before packing has occurred. More specifically, MAGNUM propellant loading requirements are as follows:

The pelleted segment of the propellant charge would be preweighted and charged into the cartridge

case. The uniformity of this preweighting will be, in part, a function of the individual pellet weight since total charge weight can only be held to plus or minus one half that of an individual pellet. Some vibration of the case would then be required to settle the pellets but natural vibration occurring in high speed automatic loaders may be sufficient to accomplish this. Under conditions of maximum pellet loading, positive restraint may be provided by a plunger which is allowed to travel with the case and removed just prior to addition of the granular propellant increment.

Loading of the granular propellant increment can be accomplished by standard volumetric charging procedures. However, the vibration requirement is more critical for proper settling of the granular propellant and it must be assumed that special vibrator equipment and positive pressure applied by a plunger would be required to assure rapid settling.

It should be noted that the complexity of the loading of the MAGNUM charge increases in direct proportion to the total charge weight. The process discussed above is that which would be required for a mixed propellant charge which approach this maximum. For charges involving lesser levels of the pelleted component, production loading operations could be

simplified and when the consolidated charge is a small enough proportion of the total, the direct single step addition of a premixed blend of the granular and pelleted components should be feasible.

The overall conclusion is that because of the additional processing steps, the unit cost of a MAGNUM propellant would be higher than that of a granular propellant. However, since propellant cost is but a small fraction of the total round cost, the performance benefits thus obtained would override the resulting minor incremental cost increase.

CONCLUSIONS AND RECOMMENDATION

1. The MAGNUM BRAVO principle of a propellant charge consisting of a granular component plus a pelleted component, the latter so coated as to delay its ignition, has been demonstrated as a practical approach to the design of a high loading density propellant suited for use with conventional ammunition components.

2. The MAGNUM combination of propellants permits the loading of a 20% higher propellant charge weight with further increases possible through the use of somewhat more complex loading procedures.

3. The 20% increase in propellant charge weight which was obtained with the MAGNUM concept results in a 175 fps increase in velocity in the 40,000 to 50,000 psi chamber pressure range. This represents a 7% increase in muzzle velocity over that which can be obtained with granular propellants.

4. When used with a short base projectile, the MAGNUM propellant charge permits a 50% increase in charge weight and a 300 fps velocity increase at 50,000 psi chamber pressure. This represents an 11% muzzle velocity increase over that which can be obtained in the standard round with granular propellants.

5. The ballistic levels quoted above were obtained at thermochemical efficiencies approaching those of well developed conventional propellants indicating that the MAGNUM system is subject to optimization by well established methods. Further incremental improvements in velocity levels should thus be quite feasible by additional tailoring of the propellant system to the specific round.

6. The standard 30mm WECOM ignition system is not adequate for satisfactory low temperature functioning with the MAGNUM propellant system. Improvement is therefore required if work is to continue in the 30mm WECOM system.

7. The MAGNUM concept has been demonstrated to be a practical approach to obtaining significant velocity increases with conventional ammunition components. It is recommended that this work be continued in an appropriate standardized military cartridge where the indicated muzzle velocity increase will result in meaningful improvements in exterior and terminal ballistic performance. Some obvious candidates include:

a) Upgraded armor penetration performance with the M-139 gun system for VRFWS/S.

b) Reduced time of flight for M-50 Series 20mm ammunition in the air-to-air and/or air defense roles.

c) Increased projectile weight (and lethality) without a velocity trade-off for M-50 Series 20mm Ammunition in the air-to-ground role.

d) Extended range for the Advanced Attack Helicopter gun system.

APPENDIX A

THE MVEL CALCULATION OF PERFORMANCE LIMITS

It is of great use in planning improvements in any system to be able to estimate the rate of improvement theoretically made possible by the variation of any factor, the absolute limits to improvement imposed by basic scientific laws, and the degree to which real performance falls short of these limits (the efficiency of the real system) because of uncontrollable, unknown effects. The first and third of these concepts depend on the second, the absolute measure of possible system performance. For guns, such an absolute measure can be derived as follows:

Gun systems are designed and operated subject to a maximum chamber pressure limitation. Maximum energy is extracted from the propellant if gas is generated in as small a volume as possible in order to obtain maximum expansion before muzzle exit. In combination these two principles imply that for maximum efficiency and muzzle velocity, the propellant should be burned in such a way as to raise the chamber pressure to maximum before the start of projectile motion and maintain it at that level until the propellant is completely consumed, after which the gas would expand adiabatically to the muzzle. To complete the picture of a gun system as an idealized heat engine, there would be no heat loss or bore resistance; all the heat energy extracted from the gas would be converted into kinetic energy of gas and projectile.

An algebraic expression succinctly approximating the ideal muzzle velocity or energy of the projectile can be derived from the following physical laws:

1. Equation of State.

2. Conservation of Energy
   Muzzle kinetic energy = Work done by gas

3. Conservation of Energy
   Work done by gas = Heat extracted from gas

4. Lagrange Approximation to the Inertial Pressure
   Gradient

The expression gives the ideal muzzle velocity or energy in terms of the elementary parameters of the gun (chamber volume, barrel volume), the propellant (impetus, ratio of specific heats, covolume), the projectile weight, the propellant weight, and the maximum pressure. This expression is embodied in a Winchester Group computer subroutine known as MVEL and will hereafter be referred to by that name.

The difference between the ideal velocity and an experimental velocity for a particular gun system is due mostly to the fact that real propellants do not burn in such a way as to produce a constant pressure until burnout. This cause would be almost totally responsible for the variation in this difference between two propellants having the same thermochemical characteristics. Consequently, it is useful to define the ratio of experimental to ideal muzzle energy as the propellant-burning (or MVEL) efficiency, and to use this quantity (or its square root, the MVEL velocity ratio) as a measure of propellant burn rate control. Improved propellant-performance, or the prospects thereof, in a given gun configuration, can then be analyzed as resulting from improved efficiency (in the above sense), or improved thermochemical properties, or both.

MVEL calculations of the ideal velocity of three empirically chosen propellant formulations were made for ammunition conditions

using both the standard and special short slug projectiles. These are summaried in Tables A-1 and A-2 and graphical representations of the standard projectile calculations are made in Figures A-I thru A-X. These calculations ignore such factors as grain size and shape and such system characteristics as shot start and bore resistance depending only upon the thermochemical properties of the propellant and upon system characteristics such as projectile weight, bore diameter, chamber volume and barrel length. The calculation then assumes a charge weight of propellant and a maximum pressure level and gives an ideal velocity. By systematically varying chemical composition, charge weight and pressure level, the overall performance level of the system can be described in some detail.

For example, it may be seen by reference to Figure A-I and a propellant with a 5% deterrent level when fired at a charge weight of 650 grains to a pressure limit of 20,000 psi has an ideal velocity of about 2540 fps. This is the 100% efficiency level and should not be expected in real life. Experience with well designed propellants indicate that efficiency levels of 91% are a reasonable goal. Thus the actual velocity which should be accepted as satisfactory under the conditions quoted is about 2315 fps. Proceeding in this general manner it is possible to judge the effectiveness of any individual propellant system fired during the course of the present program, interpolating to adjust for the actual chemical compositions of the propellants employed and the pressure levels measured.

TABLE A-1

30mm WECOM

MVEL Study with Standard Projectile

Bore Dia. = 1.181"
Cham. Vol. = 2.642 in^3
Bar. Len. = 48.5"
Proj. Wgt. = 3400 gr.

Propellant = 11% NG, 4% misc.
0, 5, 10% DBP
remainder NC

Propellant	Propell. Charge (grains)	Maximum Pressure (psi) 20,000 Vel. fps	30,000 Vel. fps	40,000 Vel. fps	50,000 Vel. fps	60,000 Vel. fps
0% DBP	600	2546	2717	2822	2895	2950
361, 148 ft lbs/lb.	650	2608	2793	2907	2987	3047
1.227 gamma	700	2664	2864	2987	3074	3139
25.13 in^3/lb.	750	2715	2929	3061	3154	3225
	800	2761	2989	3130	3230	3306
5% DBP	600	2478	2634	2730	2798	2848
337, 125 ft lbs/lb.	650	2540	2711	2815	2889	2944
1.240 gamma	700	2597	2781	2894	2974	3034
25.82 in^3/lb.	750	2649	2846	2968	3054	3119
	800	2697	2907	3037	3129	3199
10% DBP	600	2389	2529	2615	2675	2720
307, 461 ft lbs/lb.	650	2452	2605	2698	2764	2814
1.254 gamma	700	2510	2675	2776	2848	2902
26.51 in^3/lb.	750	2563	2740	2849	2927	2985
	800	2612	2801	2918	3001	3063

TABLE A-2

30mm WECOM

MVEL Study with Short Projectile

Bore Dia. = 1.181"
Cham. Vol. = 3.252 in^3
Bar. Len. = 48.5"
Proj. Wgt. = 3400 gr.

Propellant = 11% NG, 4% misc.
0, 5 or 10% DBP
remainder NC

Propellant	Propell. Charge (grains)	Maximum Pressure (psi) 30,000 psi Vel. fps	40,000 psi Vel. fps	50,000 psi Vel. fps	60,000 psi Vel. fps
0% DBP	600	2698	2797	2865	2916
361, 148 ft lbs/lb.	650	2775	2883	2959	3015
1.227 gamma	700	2864	2964	3046	3107
25.13 in^3/lb.	750	2911	3039	3127	3194
	800	2972	3108	3204	3276
	850	3029	3174	3276	3353
	900	3081	3235	3343	3453
	950	3130	3293	3408	3494
	1000	3176	3347	3468	3560
5% DBP	600	2615	2706	2768	2814
337, 125 ft lbs/lb.	650	2692	2791	2860	2911
1.240 gamma	700	2763	2871	2946	3002
25.82 in^3/lb.	750	2829	2945	3027	3088
	800	2890	3015	3102	3168
	850	2947	3080	3174	3245
	900	3000	3142	3241	3317
	950	3050	3200	3305	3385
	1000	3096	3254	3366	3451
10% DBP	600	2509	2590	2645	2686
307, 461 ft lbs/lb.	650	2585	2674	2736	2781
1.254 gamma	700	2656	2753	2820	2870
26.51 in^3/lb.	750	2722	2826	2899	2954
	800	2783	2895	2974	3033
	850	2841	2960	3045	3108
	900	2894	3022	3111	3179
	950	2944	3080	3175	3247
	1000	2922	3134	3235	3311

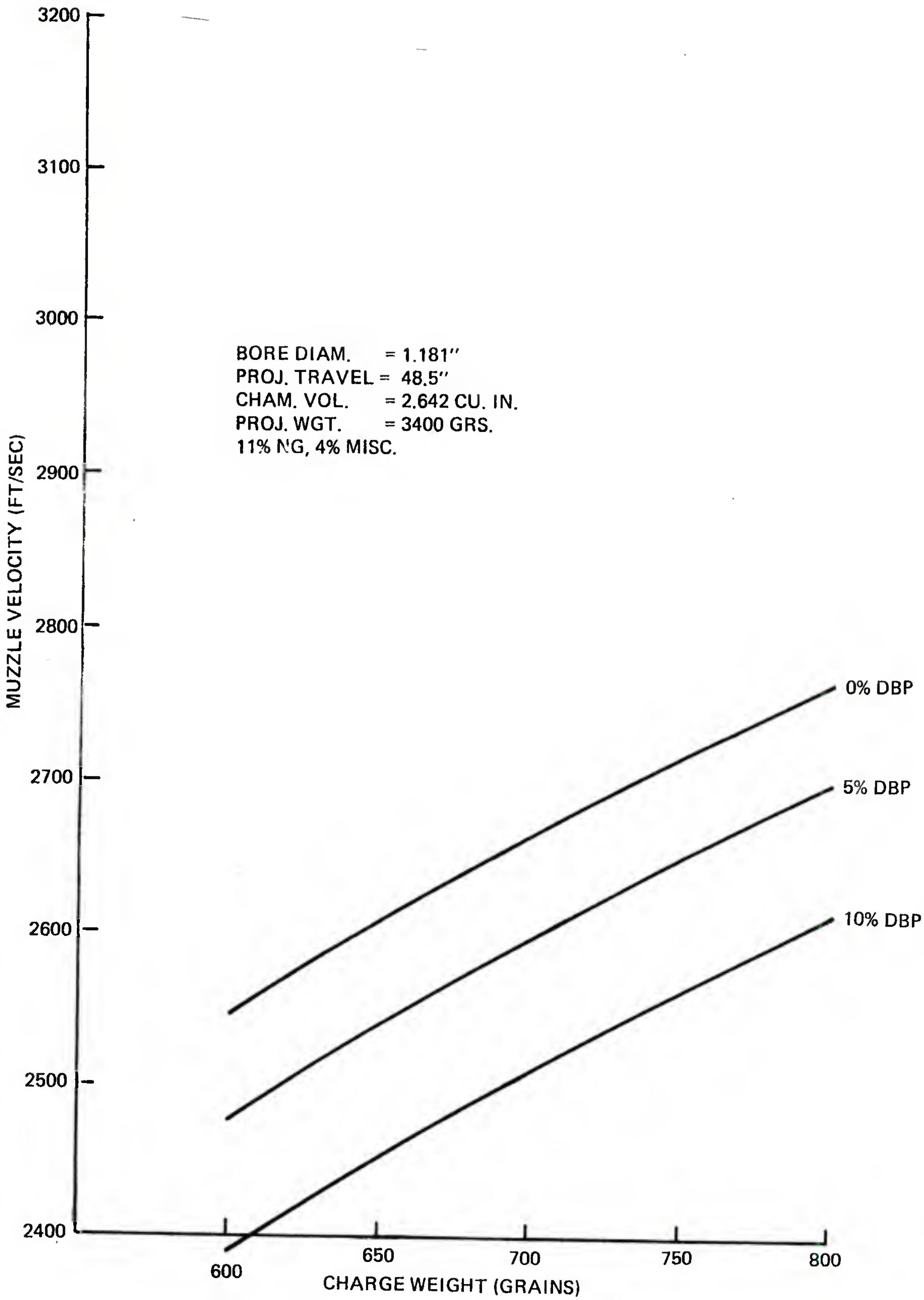


Figure A-1. 30mm WECOM - MVEL Study
20,000 psi Maximum Pressure

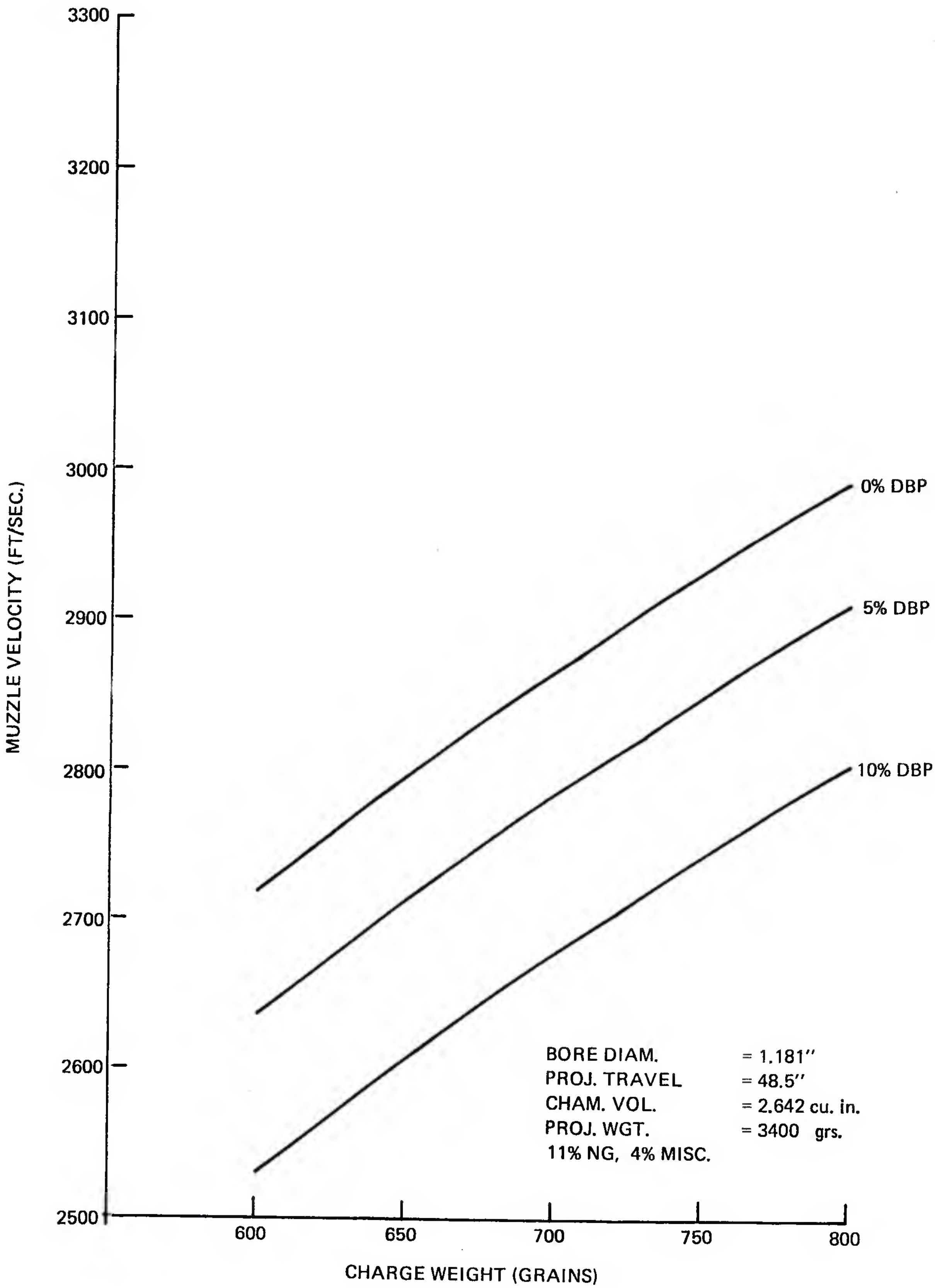


Figure A-2. 30mm WECOM - MVEL Study
30,000 psi Maximum Pressure

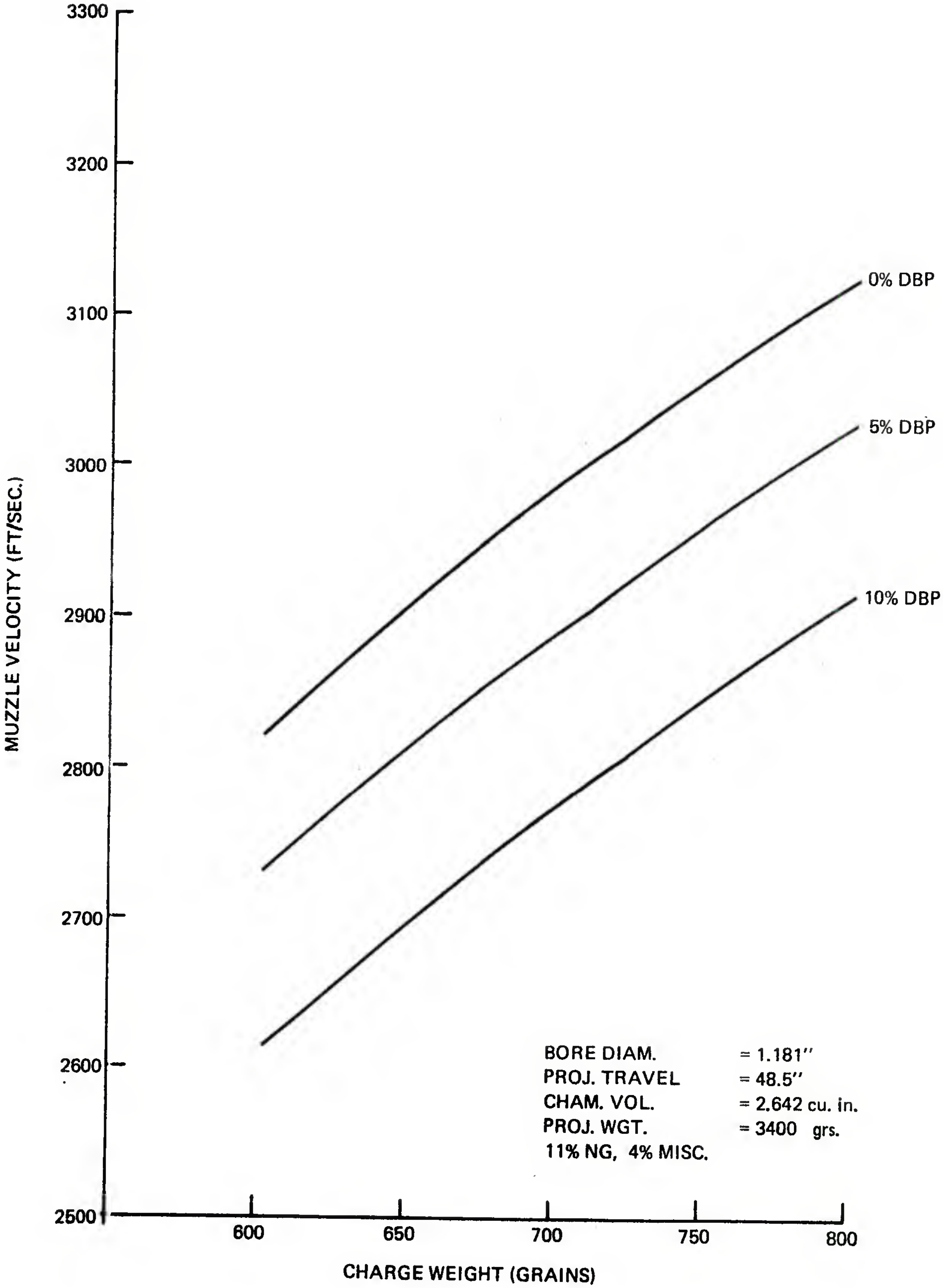


Figure A-3. 30mm WECOM - MVEL Study
40,000 psi Maximum Pressure

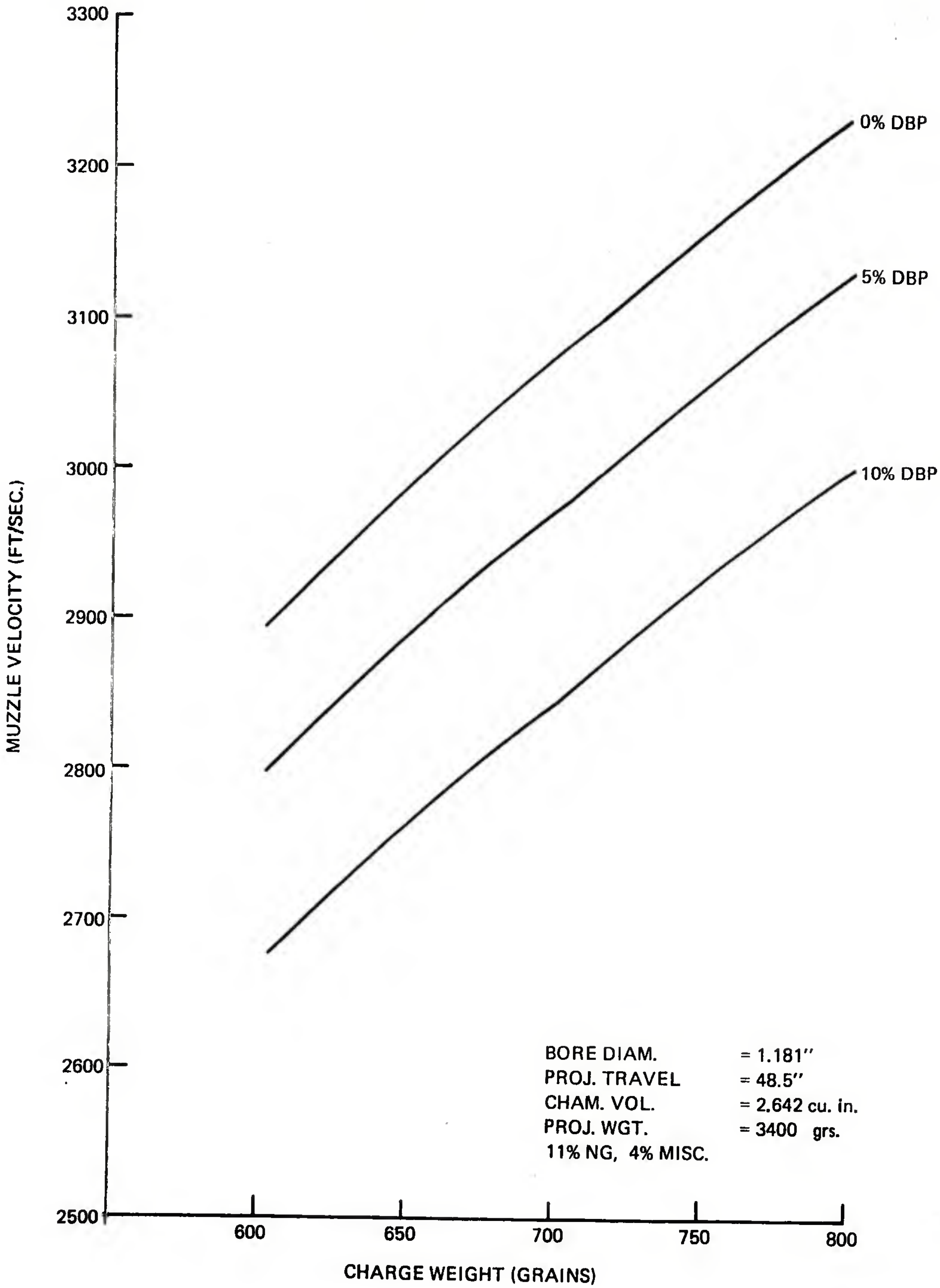


Figure A-4. 30mm WECOM - MVEL Study
50,000 psi Maximum Pressure

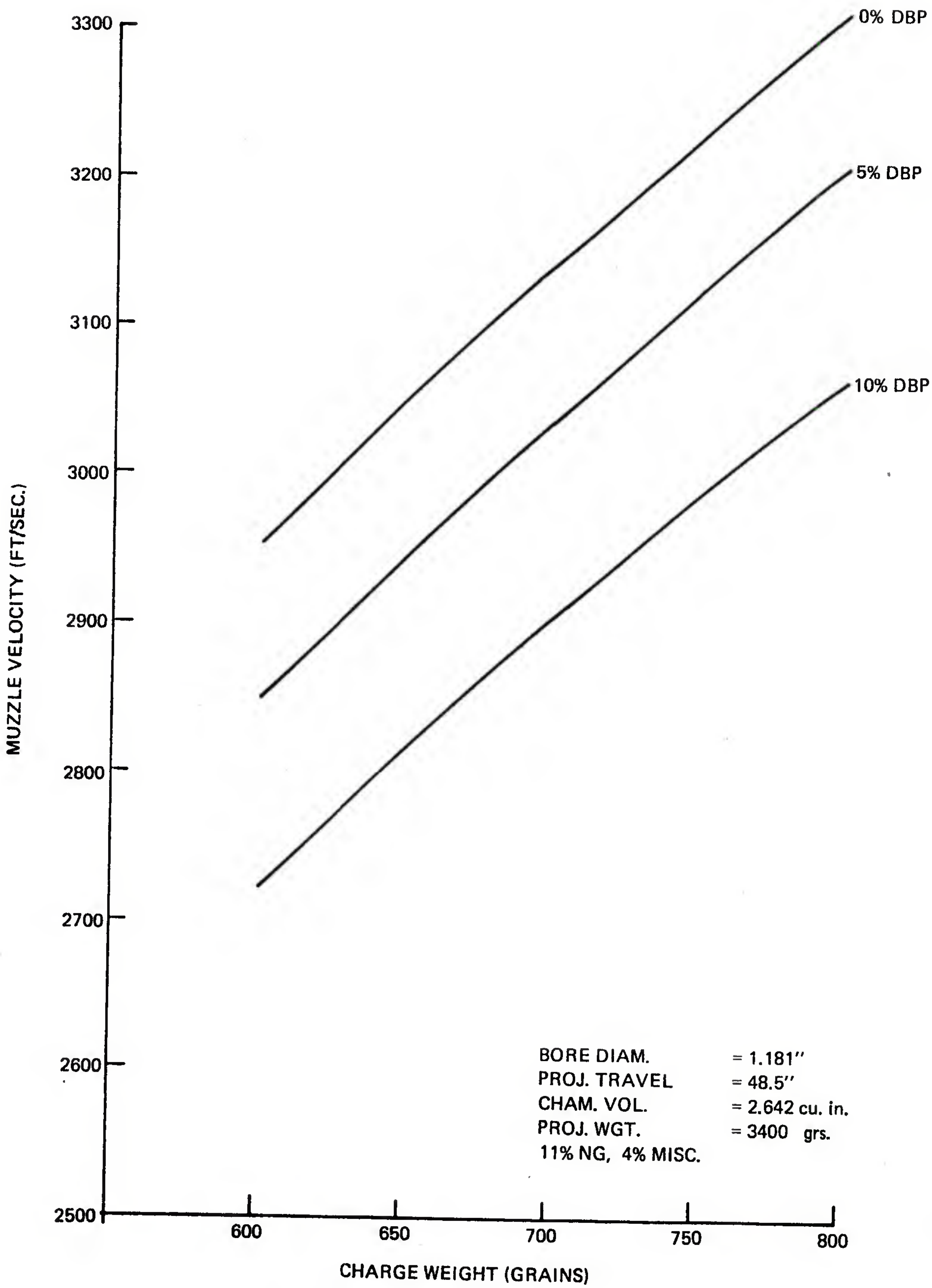


Figure A-5. 30mm WECOM - MVEL Study
60,000 psi Maximum Pressure

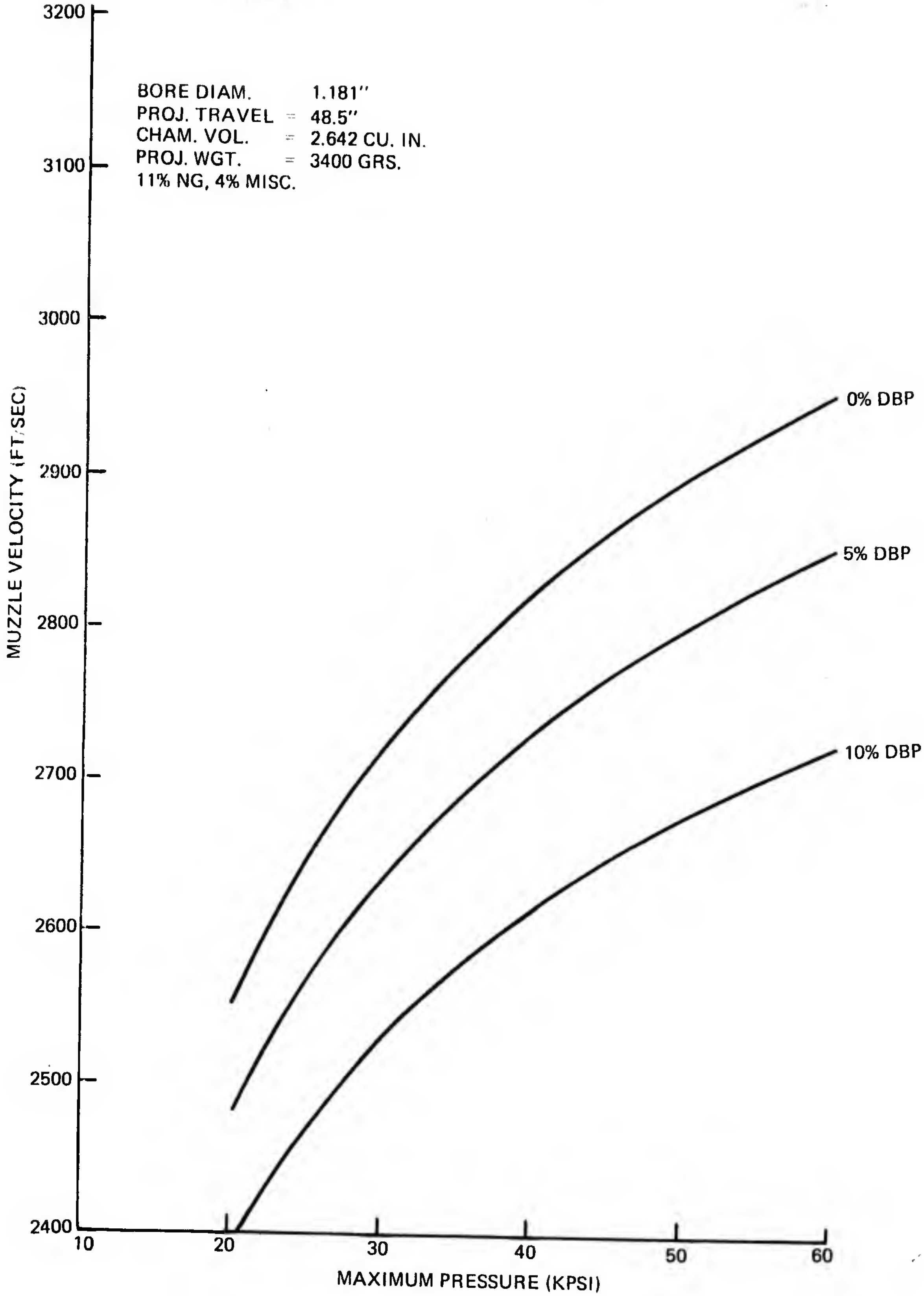


Figure A-6. 30mm WECOM - MVEL Study
600 Grain Charge Weight

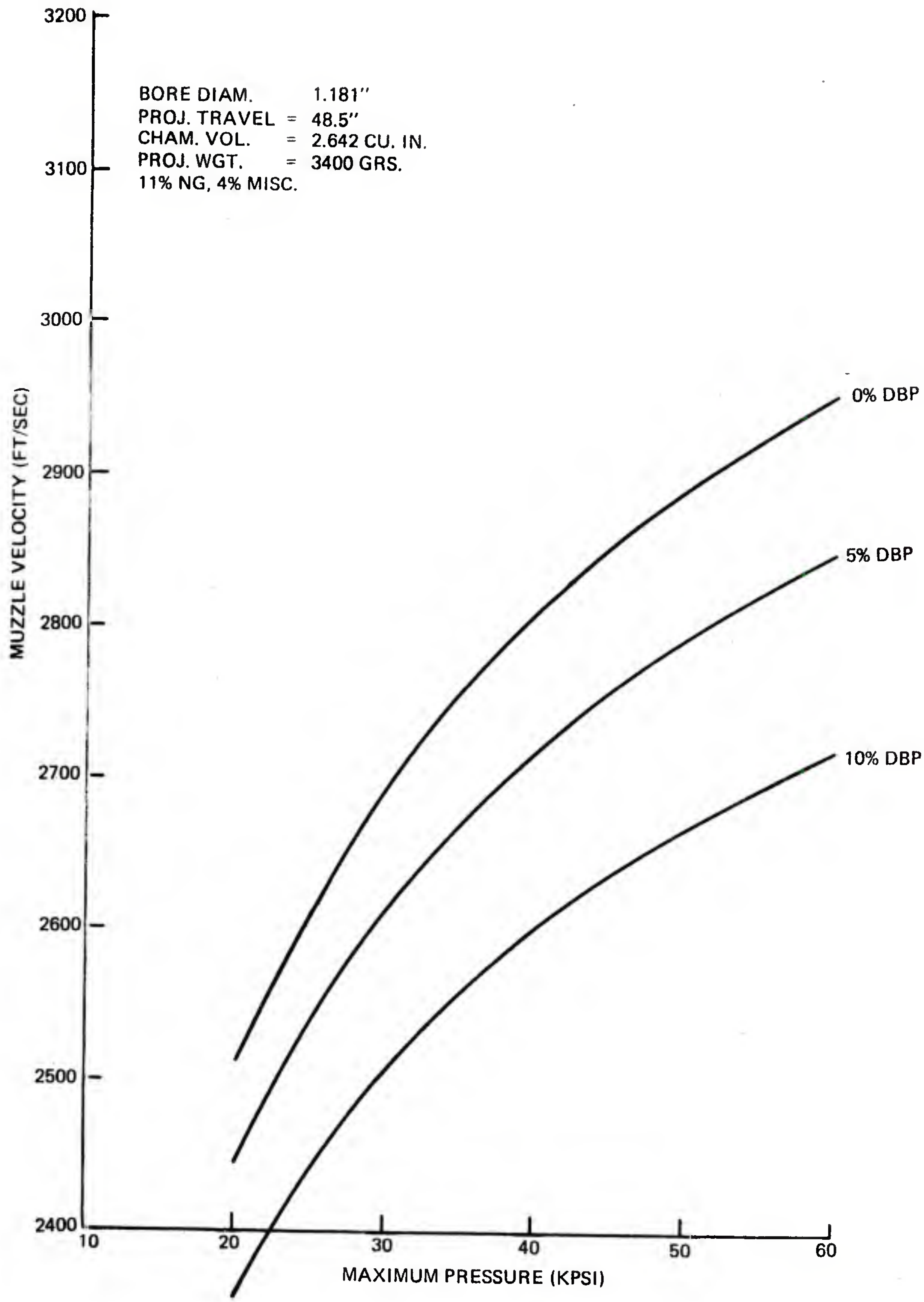


Figure A-7. 30mm WECOM - MVEL Study
650 Grain Charge Weight

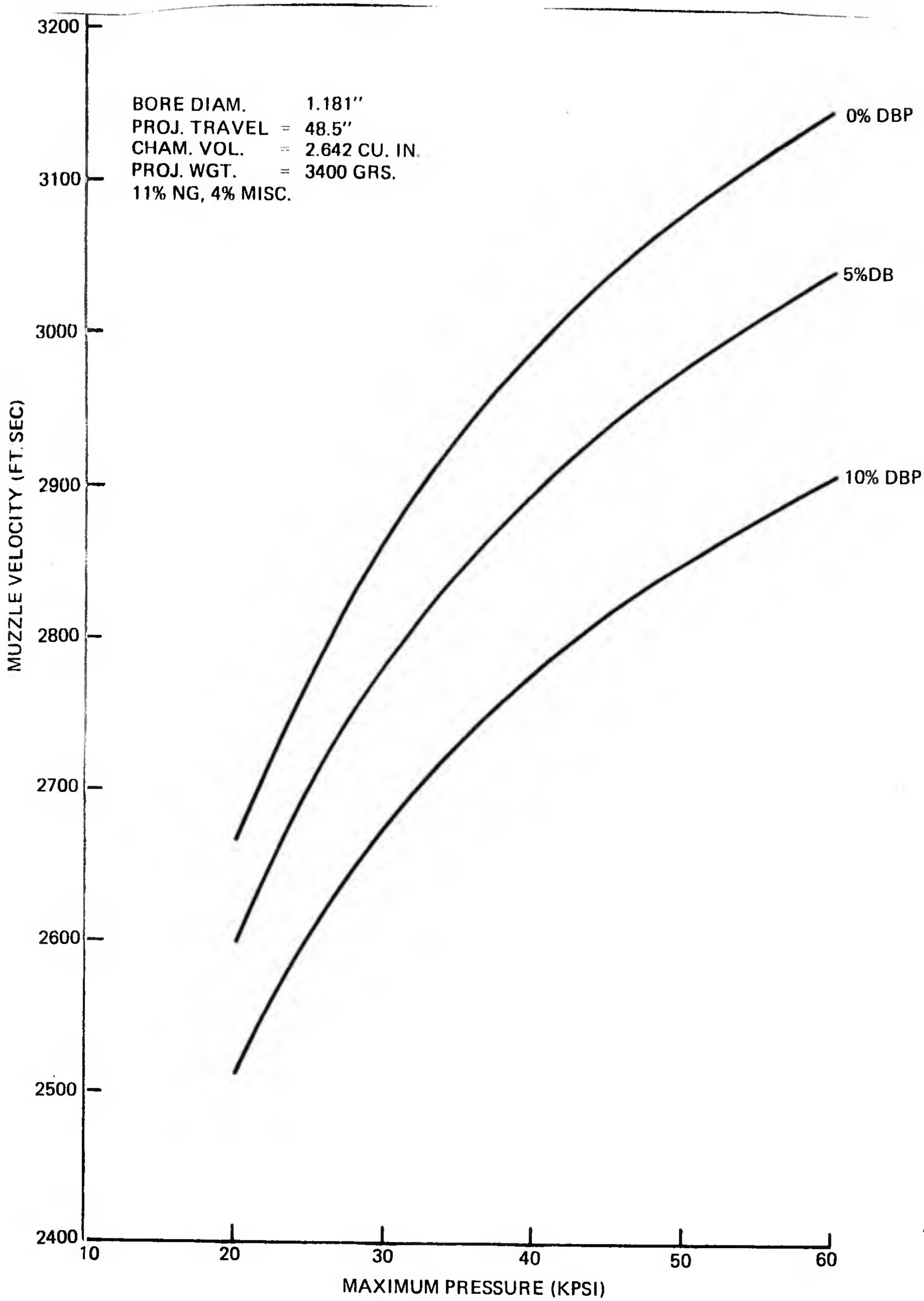


Figure A-8. 30mm WECOM - MVEL Study
700 Grain Charge Weight

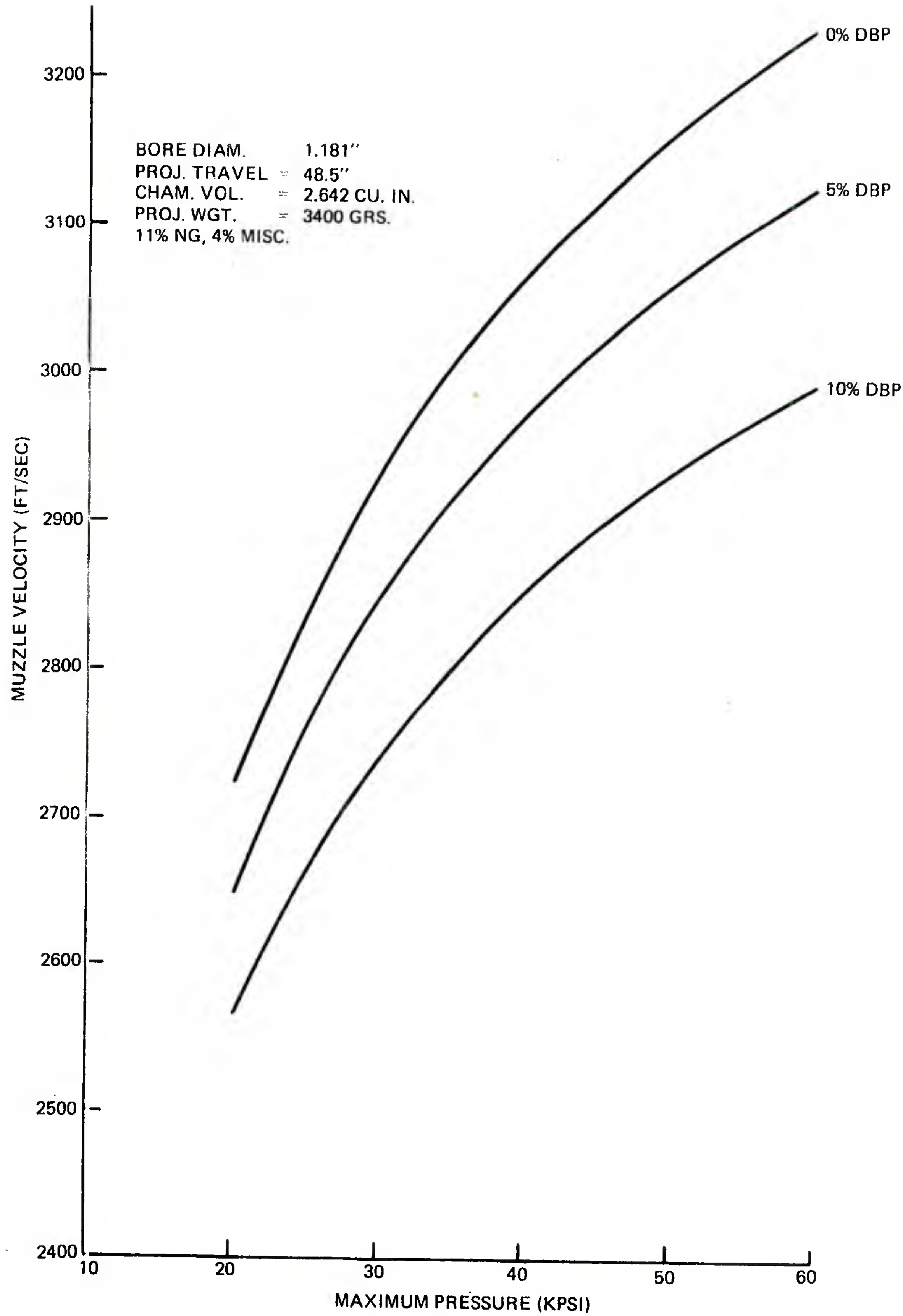


Figure A-9. 30mm WECOM - MVEL Study
750 Grain Charge Weight

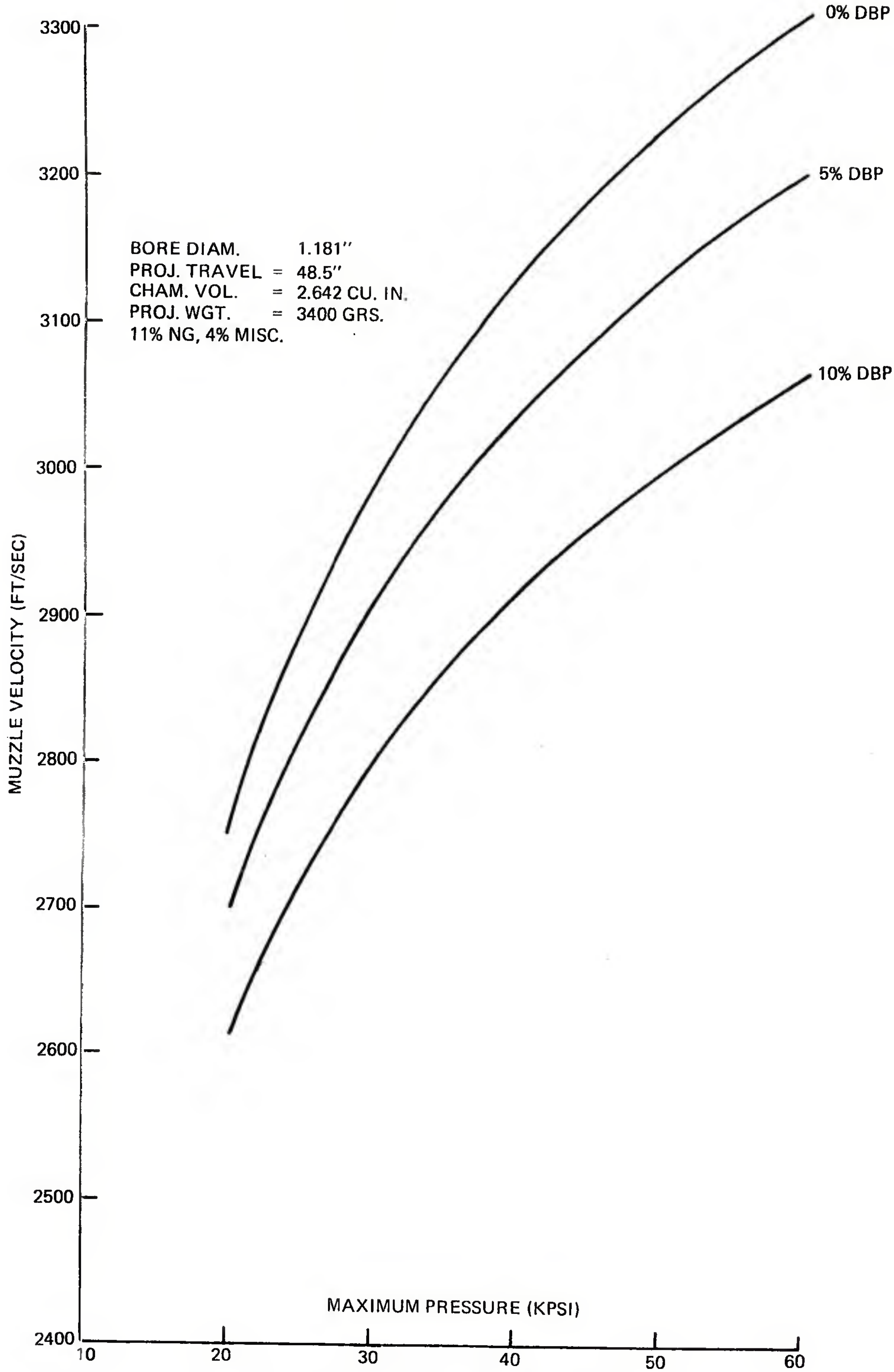


Figure A-10. 30mm WECOM - MVEL Study
800 Grain Charge Weight

APPENDIX B

INTERIOR BALLISTIC CALCULATIONS SYSTEM ANALYSIS

As an aid to interpretation of the experimental data obtained, the 30mm WECOM system with various Magnum propellant combinations and varying free run conditions was subjected to interior ballistic computations using the Winchester Interior Ballistics Computer Model INBAL as described in references 1 and 2. This computer program is designed to simulate the distinctive combustion characteristics of BALL POWDER that result from its unusual geometry and the sharp variations in chemical composition along the radius of the grain.

In addition to variations in chemical gradient, grain size, degree of web reduction and bore resistance, special provisions were made for variation in free run and delay between ignition of the granular and pelleted propellant charges.

Table B-1 defines the ammunition-gun system under investigation; Table B-2 details the propellant variations which were considered; and Table B-3 shows simulated closed bomb characteristics of several theoretical propellants.

TABLE B-1

GUN-AMMUNITION SYSTEM DEFINITION

Bore Diameter	- 1.181 inches
Bore Area	- 1.096 square inches
Total Projectile Travel	- 48.5 inches
Case Volume	- 2.642 cubic inches
Projectile Weight	- 3400 grains

Bore Resistance versus Projectile Travel

Bore Resistance* (lbs)	Projectile Travel (inches) RL 0 No Free Run	RL .5 0.5" Free Run	RL 1 1.0" Free Run	RL 2 2.0" Free Run	RL 4 4.0" Free Run
4237	0	.5	1.0	2.0	4.0
3390	2.0	2.5	3.0	4.0	6.0
2542	5.0	5.5	6.0	7.0	9.0
1685	9.0	9.5	10.0	11.0	13.0
847	14.0	14.5	15.0	16.0	18.0
424	18.0	18.5	19.0	20.0	22.0
339	21.0	21.5	22.0	23.0	25.0
339	48.5	48.5	48.5	48.5	48.5
Total Work (ft-lbs)	3695	3681	3667	3638	3582

Bore Resistance (lbs)	Projectile Travel (inches) RH 0 No Free Run	RH 2 2.0" Free Run
8474	0	2.0
6780	2.0	4.0
5084	5.0	7.0
3390	9.0	11.0
1694	14.0	16.0
848	18.0	20.0
678	21.0	23.0
678	48.5	48.5
Total Work (ft-lbs)	7390	7277

*RH bore resistance is double that of RL condition. As an aid to interpretation, the designation RL denotes the lower resistance factor and RH denotes the higher resistance factor.

TABLE B-2

ASSUMPTIONS FOR INTERIOR BALLISTIC CALCULATIONS

B. Propellant Definition

General Characteristics

	All Except A15% Gradient with R Grain Configuration	A15% Gradient with R Grain Configuration
Nitroglycerine	11.0%	11.0%
Dibutylphthalate	5.0%	3.6%
Minor Constituents	4.0%	4.0%
Nitrocellulose	80.0%	81.4%
Impetus	337,200 ft-lb/lb	344,500 ft-lb/lb
Flame Temperature	2870°K	2990°K
Average Molecular Weight of Combustion Gases	23.678	24.140

Deterrent Gradient - Assumes uniform dibutylphthalate (DBP) concentration from grain surface to gradient start point

Designation	A10%	A15%	A20%	B10%	B15%	B20%
DBP Surface Layer Concentration	10%	15%	20%	10%	15%	20%
Gradient Start Point*	81.025%	89.834%	94.169%	72.048%	84.233%	90.077%
Gradient End Point*	77.691%	84.834%	87.502%	68.715%	79.233%	83.410%

*% of web radius

Grain Configuration

Designation	S21"	S18"	S15"	S12"	R14"	R12"	R10"	R8"
Base Grain Diameter	.021"	.018"	.015"	.012"	.021"	.018"	.015"	.012"
Web	.021"	.018"	.015"	.012"	.014	.012"	.010"	.008"

"S" samples are spherical. "R" samples are rolled to reduce grain diameter by one third.

TABLE B-3

SIMULATED CLOSED BOMB CHARACTERISTICS OF

THEORETICAL PROPELLANTS

Loading Density - 0.2245 gms/cc

Initial Pressure - 1,000 psi

Initial Temperature - 1,000°K

Propellant	DBP	Maximum Pressure (psi)	Time to Peak (ms)	Relative Quickness* References A15%-S21"	B15%-R14"
A15%-S21"	5.0%	43,291	3.2407	1.000	.862
A15%-S18"	5.0%	43,291	2.7777	1.167	1.005
A15%-S15"	5.0%	43,291	2.3148	1.400	1.206
A15%-S12"	5.0%	43,291	1.8518	1.750	1.508
B15%-R14"	5.0%	43,283	2.7921	1.161	1.000
B15%-R12"	5.0%	43,283	2.3933	1.354	1.166
B15%-R10"	5.0%	43,283	1.9944	1.625	1.400
B15%-R8"	5.0%	43,283	1.5955	2.031	1.750
A15%-R14"	3.6%	44,207	2.5619	1.265	1.090
A15%-R12"	3.6%	44,207	2.1959	1.476	1.272
A15%-R10"	3.6%	44,207	1.8299	1.771	1.526
A15%-R8"	3.6%	44,207	1.4640	2.214	1.907

*Ratio of times to peak pressure as compared with reference propellants, **A15%-S21"** and **B15%-R14"**.

An initial set of calculations was made to establish the general effects of variations in (A) grain size and deterrent gradient, (B) bore resistance and free run and (C) charge weight. These are shown in Table B-4.

As may be seen from the "A" section of the Table, a reduction in the deterrent layer concentration results in higher peak pressures and reduced ballistic efficiency. The presence in the calculation of two pressure peaks is the result of the change of grain composition with diameter. Thus, the initial grain has the largest surface area but its burning rate is less than that of the core due to the presence of deterrent. When the deterrent concentration is low, the effect of this change in composition is minor but when the deterrent is concentrated near the surface, the change of burn rate occurs while there is still sufficient grain surface area to so increase the total burn rate that a second pressure peak develops. When the deterrent layer is thin enough , this may result in the second peak being greater than the first. All three conditions are represented in the calculations presented. The A15% and B15% gradient conditions most nearly match the propellant used in the experimental program so the balance of the data is presented with these.

Section B permits an examination of the effects of restrictions on projectile movement. A comparison of the RL 0 and RL 1 conditions shows the change introduced by a free run; the result

TABLE B-4

GENERAL SYSTEMS CHARACTERIZATION

	Charge (grains)	Propellant Type	Bore Resistance	Peak Pressure (psi) First	Peak Pressure (psi) Second	Muz. Vel (fps)	MVEL (%)	Unburned Powder (%)
A.	630	A10%-S21"	RL0	66,003	-	2518	85.26	1.30
	630	A15%-S21"	RL0	39,523	35,517	2453	88.33	0.94
	630	A20%-S21"	RL0	23,723	31,800	2404	88.96	0.69
	630	B10%-S21"	RL0	69,102	-	2591	87.97	0.0
	630	B15%-S21"	RL0	41,190	39,908	2523	90.38	0.0
	630	B20%-S21"	RL0	24,612	34,368	2459	90.09	0.0
B.	630	A15%-S21"	RL0	39,523	35,517	2453	88.33	0.94
	630	A15%-S21"	RL1	29,961	24,885	2337	87.20	1.44
	630	A15%-S21"	RH0	47,313	47,707	2463	86.78	0.39
	630	B15%-R14"	RL0	41,190	39,908	2523	90.38	0.0
	630	B15%-R14"	RL1	31,465	28,157	2413	89.43	0.0
	630	B15%-R14"	RH0	49,069	52,357	2525	87.98	0.0
C.	560	A15%-S21"	RL0	30,575	27,992	2264	87.92	1.24
	630	A15%-S21"	RL0	39,523	35,517	2453	88.33	0.94
	700	A15%-S21"	RL0	52,807	45,951	2646	88.45	0.71
	560	B15%-R14"	RL0	31,801	31,235	2330	90.05	0.0
	630	B15%-R14"	RL0	41,190	39,908	2523	90.38	0.0
	700	B15%-R14"	RL0	55,261	52,096	2720	90.44	0.0

being, as expected, a decrease in pressure level. It should be noted that the calculation ignores crimp release force and assumes that the engraving force is constant regardless of projectile velocity. A comparison of RL 0 and RH 0 illustrates the effects of changing bore resistance.

Section C simply lists for reference the effects of changes in charge weight.

The calculations were next expanded to consider further the effects of variation in web, with the presence or absence of free run, as an independent variable. This data is shown in Table B-5 and is largely self-explanatory.

Inasmuch as the Magnum Bravo concept consists of a dual propellant charge in which the ignition and burning of the pelleted component is delayed over that of the granular component, calculations were made of the simplified case in which the burning of the granular constituent alone is considered. The calculation thus considers the pellets to be a 400 grain inert charge and proceeds with an analysis of the effects of varying the granular propellant type and weight, with and without a free run (in this case of one-half inch) as shown in Table B-6.

The data shows the strong effect of free run in lowering of peak pressure. However, its effect on time to peak pressure is minor.

TABLE B-5

WEB AND FREE RUN STUDY

Propellant Charge: 650 grains of granular propellant

Propellant	Bore Resistance	Peak Pressure (psi) First	Peak Pressure (psi) Second	Muz. Vel. (fps)	MVEL (%)	Unburned Powder (%)
A15%-S21"	RL0	42,599	38,126	2508	88.42	0.86
A15%-S18"	RL0	51,770	61,590	2673	90.57	0.01
A15%-S15"	RL0	-	101,275	2811	91.15	0.0
A15%-R14"	RL0	-	75,155	2753	90.54	0.0
B15%-R14"	RL0	44,669	42,969	2579	90.41	0.0
B15%-R12"	RL0	54,219	68,875	2724	91.32	0.0
B15%-R10"	RL0	-	111,839	2845	91.57	0.0
A15%-S21"	RL1	32,759	27,092	2397	87.35	1.31
A15%-S18"	RL1	41,039	45,399	2588	90.58	0.04
A15%-S15"	RL1	53,757	78,144	2750	91.14	0.0
A15%-R14"	RL1	-	54,136	2662	90.14	0.0
A15%-R12"	RL1	-	82,801	2793	91.05	0.0
B15%-R14"	RL1	34,521	30,709	2474	89.43	0.0
B15%-R12"	RL1	43,194	51,181	2645	91.34	0.0
B15%-R10"	RL1	56,736	88,486	2789	91.44	0.0

TABLE B-6

GRANULAR PROPELLANT BALLISTICS

Granular Propellant	Deterrent Content	Charge (Grains)	Bore Resistance	Maximum Pressure (psi)	(@ms)	Projectile Travel (in)	(fps)
A10%-S21"	5.0%	350	RL0	37,812	.375	.370	346
A15%-S21"	5.0%	350	RL0	23,854	.476	.335	256
A20%-S21"	5.0%	350	RL0	15,317	.611	.285	179
B10%-R14"	5.0%	350	RL0	39,437	.369	.377	358
B15%-R14"	5.0%	350	RL0	24,816	.468	.341	263
B20%-R14"	5.0%	350	RL0	15,773	.602	.291	185
A10%-S21"	5.0%	350	RL.5	28,689	.377	.497	365
A15%-S21"	5.0%	350	RL.5	15,854	.471	.508	276
A20%-S21"	5.0%	350	RL.5	8,456	.575	.490	200
B10%-R14"	5.0%	350	RL.5	30,108	.371	.498	374
B15%-R14"	5.0%	350	RL.5	16,590	.465	.510	283
B20%-R14"	5.0%	350	RL.5	8,831	.568	.492	205
A15%-R14"	3.6%	250	RL0	14,443	.713	.364	196
A15%-R14"	3.6%	300	RL0	18,501	.593	.357	228
A15%-R14"	3.6%	350	RL0	23,854	.476	.335	256
A15%-R14"	3.6%	250	RL.5	8,027	.717	.771	224
A15%-R14"	3.6%	300	RL.5	11,305	.581	.628	253
A15%-R14"	3.6%	350	RL.5	15,854	.471	.508	276
B15%-R14"	5.0%	250	RL0	14,876	.701	.371	202
B15%-R14"	5.0%	300	RL0	19,151	.573	.360	233
B15%-R14"	5.0%	300	RL0	24,816	.468	.341	263
B15%-R14"	5.0%	250	RL.5	8,376	.706	.770	230
B15%-R14"	5.0%	300	RL.5	11,025	.572	.628	259
B15%-R14"	5.0%	350	RL.5	16,590	.465	.510	283

Calculations next considered the added effects of pellet ignition, this time on a one inch free run (RL bore resistance) condition with 300 grains of granular propellant and 400 grains of pelleted propellant. The time delay to ignition of the pelleted propellant was the critical variable considered. Results are shown in Tables B-7 and B-8.

A summary of the ballistic data contained in Tables B-7 and B-8 is presented in Table B-9. It may be observed that when a comparatively fast granular powder, A15%-S12", is tried with a range of pelleted powders, the best MVEL efficiency is found with the faster pelleted powders. The use of a faster granular powder, A15%-R8", leads to the same conclusion with a slight improvement in overall efficiency. **In all propellant combinations, it is observed that pellet ignition delay is a critical factor affecting peak pressure and projectile velocity.**

With respect to pelleted propellant ignition delay, there is a general observation which may be made. As ignition delay increases, efficiency first rises slowly then begins to fall as the pellets fail to burn fast enough to cause a pressure peak of its own. Further increase in ignition delay results in unburned propellant and a drastic decrease in MVEL efficiency.

TABLE B-7

IGNITION TIME ANALYSIS

Propellant

300 Grains Granular A15%-S12"
400 Grains Pelleted A15%-S18", A15%-S15", A15%-S12", B15%-R8", A15%-R8"

Bore Resistance

RL 1 (1.0" free run)

Condition	Time (ms)	Projectile Travel (in)	Projectile Velocity (fps)	Pressure (psi)	Unburned Powder (%)	MVEL (%)
Granular Propellant Only						
Peak Pressure	.637	1.864	713	33,603		
A. Pelleted Propellant: A15%-S18"						
Ignited at 0.40 ms.						
Peak Pressure	.609	1.811	863	58,452		
Burn Out 1	1.070	10.293	2012	21,883		
Muzzle Exit	2.365	48.5	2699	3,484	0.32	89.21
Ignited at 0.60 ms.						
Peak Pressure	.703	2.494	869	39,182		
Burn Out 1	1.330	13.237	1834	15,581		
Muzzle Exit	2.646	48.5	2482	3,959	2.07	86.01
Ignited at 0.80 ms.						
Peak Pressure*	.637	1.864	713	33,603		
Burn Out 1	1.608	17.490	1726	8,720		
Muzzle Exit	2.900	48.5	2209	4,001	9.89	78.13

* Peak pressure occurs prior to ignition of pelleted propellant

TABLE B-7 (cont'd.)

Condition	Time (ms)	Projectile Travel (in)	Projectile Velocity (fps)	Pressure (psi)	Unburned Powder (%)	MVEL (%)
B. Pelleted Propellant: A15%-S15"						
Ignited at 0.40 ms.						
Peak Pressure	.675	2.675	1177	65,830		
Burn Out 1	.993	9.173	2080	26,043		
Burn Out 2	2.091	42.335	2747	3,867		
Muzzle Exit	2.277	48.5	2786	3,243	0.0	90.96
Ignited at 0.60 ms.						
Peak Pressure	.711	2.584	895	40,804		
Burn Out 1	1.250	11.913	1875	19,387		
Muzzle Exit	2.561	48.5	2585	3,837	0.13	89.09
Ignited at 0.80 ms.						
Peak Pressure*	.637	1.864	713	33,603		
Burn Out 1	1.541	16.278	1743	11,245		
Muzzle Exit	2.832	48.5	2321	4,291	3.27	82.09

*Peak pressure occurs prior to ignition of pelleted propellant

TABLE B-7 (cont'd.)

Condition	Time (ms)	Projectile Travel (in)	Projectile Velocity (fps)	Pressure (psi)	Unburned Powder (%)	MVEL (%)
C. Pelleted Propellant: A15%-S12"						
Ignited at 0.40 ms.						
Peak Pressure	.645	2.388	1196	87,452		
Burn Out 1	.917	8.172	2163	29,772		
Burn Out 2	1.164	15.094	2468	13,608		
Muzzle Exit	2.189	48.5	2862	3,003	0.0	90.95
Ignited at 0.60 ms.						
Peak Pressure	.720	2.690	930	43,412		
Burn Out 1	1.167	10.591	1927	23,906		
Burn Out 2	1.909	30.876	2507	6,440		
Muzzle Exit	2.474	48.5	2674	3,587	0.0	91.45
Ignited at 0.80 ms.						
Peak Pressure*	.637	1.864	713	33,603		
Burn Out 1	1.456	14.763	1769	14,816		
Muzzle Exit	2.748	48.5	2438	4,250	0.13	86.25

*Peak pressure occurs prior to ignition of pelleted propellant

Condition	Time (ms)	Projectile Travel (in)	Projectile Velocity (fps)	Pressure (psi)	MVEL (%)
D. Pelleted Propellant: B15%-R8"					
Ignited at 0.50 ms.					
Peak Pressure	.749	3.305	1236	63,326	
Burn Out 2	.995	8.192	1990	32,326	
Burn Out 1	1.026	8.947	2049	28,848	
Muzzle Exit	2.320	48.5	2787	3,241	91.26
Ignited at 0.55 ms.					
Peak Pressure	.805	3.910	1273	53,237	
Burn Out 1	1.086	9.562	1993	27,464	
Burn Out 2	1.102	9.941	2019	26,262	
Muzzle Exit	2.386	48.5	2742	3,379	91.56
Ignited at 0.60 ms.					
Peak Pressure	.722	2.710	936	43,891	
Burn Out 1	1.152	10.336	1938	25,317	
Burn Out 2	1.234	12.313	2055	20,826	
Muzzle Exit	2.457	48.5	2692	3,532	91.94
Ignited at 0.65 ms.					
Peak Pressure	.745	2.941	949	38,252	
Burn Out 1	1.223	11.257	1887	22,866	
Burn Out 2	1.395	15.380	2095	16,351	
Muzzle Exit	2.529	48.5	2637	3,695	91.66

TABLE B-7 (cont'd.)

Condition	Time (ms)	Projectile Travel (in)	Projectile Velocity (fps)	Pressure (psi)	MVEL (%)
E. Pelleted Propellant: A15%-R8"					
Ignited at 0.50 ms.					
Peak Pressure	.722	2.937	1189	75,870	
Burn Out 2	.919	6.740	1936	41,031	
Burn Out 1	.989	8.421	2090	30,791	
Muzzle Exit	2.273	48.5	2839	3,219	90.82
Ignited at 0.55 ms.					
Peak Pressure	.772	3.455	2117	63,569	
Burn Out 2	1.014	8.1916	1967	33,313	
Burn Out 1	1.046	8.9729	2031	29,627	
Muzzle Exit	2.339	48.5	2795	3,358	91.00
Ignited at 0.60 ms.					
Peak Pressure	.829	4.108	1258	51,912	
Burn Out 1	1.109	9.671	1972	27,923	
Burn Out 2	1.129	10.146	2006	26,433	
Muzzle Exit	2.409	48.5	2746	3,509	91.40
Ignited at 0.65 ms.					
Peak Pressure	.892	4.924	1305	42,109	
Burn Out 1	1.177	10.511	1918	25,538	
Burn Out 2	1.267	12.659	2047	20,783	
Muzzle Exit	2.479	48.5	2693	3,668	91.92

TABLE B-8

IGNITION TIME ANALYSIS

Propellant

300 Grains Granular A15%-R8"
400 Grains Pelleted B15%-R8", A15%-R8"

Bore Resistance

RL 1 (1.0" free run)

Condition	Time (ms)	Projectile Travel (in)	Projectile Velocity (fps)	Pressure (psi)	MVEL (%)
Granular Propellant Only					
Peak	.519	1.163	680	54,427	
A. Pelleted Propellant: B15%-R8"					
Ignited at 0.50 ms.					
Peak Pressure	.579	1.743	929	67,728	
Burn Out 1	.675	3.043	1317	63,934	
Burn Out 2	.982	9.689	2160	25,759	
Muzzle Exit	2.223	48.5	2828	3,219	91.62
Ignited at 0.55 ms.					
Peak Pressure	.601	1.964	955	56,002	
Burn Out 1	.733	3.825	1370	45,582	
Burn Out 2	1.178	13.773	2219	17,545	
Muzzle Exit	2.308	48.5	2753	3,449	91.02
Ignited at 0.60 ms.					
Peak Pressure*	.519	1.163	680	54,427	
Burn Out 1	.757	4.118	1347	36,505	
Burn Out 2	1.423	19.218	2274	12,207	
Muzzle Exit	2.393	48.5	2675	3,686	88.71
Ignited at 0.65 ms.					
Peak Pressure*	.519	1.163	680	54,427	
Muzzle Exit	2.473	48.5	2596	3,918	86.08

*Peak pressure occurs prior to ignition of pelleted propellant.

TABLE B-8 (cont'd.)

Condition	Time (ms)	Projectile Travel (in)	Projectile Velocity (fps)	Pressure (psi)	MVEL (%)
B. Pelleted Propellant: A15%-R8"					
Ignited at 0.50 ms.					
Peak Pressure	.653	2.718	1267	77,169	
Burn Out 1	.687	3.254	1426	74,271	
Burn Out 2	.897	7.830	2109	33,426	
Muzzle Exit	2.180	48.5	2880	3,193	91.58
Ignited at 0.55 ms.					
Peak Pressure	.600	1.954	952	56,001	
Burn Out 1	.713	3.503	1334	55,952	
Burn Out 2	1.061	11.106	2173	22,830	
Muzzle Exit	2.264	48.5	2809	3,416	92.32
Ignited at 0.60 ms.					
Peak Pressure*	.519	1.163	680	54,427	
Burn Out 1	.756	4.100	1348	40,135	
Burn Out 2	1.264	15.443	2230	15,942	
Muzzle Exit	2.346	48.5	2735	3,643	90.17
Ignited at 0.65 ms.					
Peak Pressure*	.519	1.163	680	54,427	
Burn Out 1	.774	4.341	1332	31,674	
Burn Out 2	1.501	20.745	2279	11,567	
Muzzle Exit	2.424	48.5	2661	3,865	87.71

*Peak pressure occurs prior to ignition of pelleted propellant.

TABLE B-9

SUMMATION TABLES B-7 and B-8

Bore Resistance

RL1 (1.0" free run)

Relative Quickness (A15%-S21" Reference)

Propellant	RQ
A15%-S18"	1.167
A15%-S15"	1.400
A15%-S12"	1.750
B15%-R8"	2.031
A15%-R8"	2.214

Granular Propellant 300 Grains	Pelleted Propellant 400 Grains	Ignition Delay (ms)	Maximum Pressure (psi)	Muzzle Velocity (fps)	MVEL (%)
A15%-S12"	A15%-S18"	0.40	58,452	2699	89.21
		0.60	39,182	2482	86.01
A15%-S12"	A15%-S15"	0.40	65,830	2786	90.96
		0.60	40,804	2585	89.09
A15%-S12"	A15%-S12"	0.40	87,452	2862	90.95
		0.60	43,412	2674	91.45
A15%-S12"	B15%-R8"	0.50	63,326	2787	91.26
		0.55	53,237	2742	91.56
		0.60	43,891	2692	91.94
		0.65	38,252	2637	91.66
A15%-S12"	A15%-R8"	0.55	63,569	2795	91.00
		0.60	51,912	2746	91.40
		0.65	42,109	2693	91.92
A15%-R8"	B15%-R8"	0.50	67,728	2828	91.62
		0.55	56,002	2753	91.02
		0.60	54,427 *	2675	88.71
A15%-R8"	A15%-R8"	0.55	56,001	2809	92.32
		0.60	54,427*	2735	90.17

*Peak pressure occurs prior to ignition of pelleted propellant.

The analysis of propellant burn rate and ignition delay interactions was continued further with an additional variable, charge weight, introduced. The pattern of these calculations is as previously shown. Table B-10 summarizes the resulting pressure-velocity relationships and the MVEL efficiencies. The data is first calculated at a 700 grain total charge and next at a 800 grain total. The granular to pelleted propellant ratio in both cases is three to four.

The data again shows that delay in ignition of the pelleted propellant has a critical effect on peak pressure and that best MVEL efficiencies are obtained when the pelleted powder is slightly faster than the granular propellant. Within the limits investigated the faster granular powder exhibits the highest MVEL efficiency. The increase in charge weight has only a small effect on overall efficiency and therefore velocities increase significantly at a given pressure level as charge weight is increased.

TABLE B-10

PROPELLANT-IGNITION TIME-CHARGE WEIGHT VARIATION

Bore Resistance: RL1 (1.0" free run)

Granular Propellant	Pelleted Propellant	Ignition Delay (ms)	Maximum Pressure (psi)	Muzzle Velocity (fps)	MVEL (%)
A. 700 Grain Total Charge - 300 grains granular and 400 grains pelleted					
A15%-S21"	A15%-S21"	0.4	27,573	2433	88.63
	A15%-S18"	0.4	33,349	2549	90.26
	A15%-S15"	0.4	46,163	2659	90.27
	A15%-S12"	0.4	67,235	2761	89.94
	A15%-S15"	0.5	38,254	2593	90.12
A15%-S12"	A15%-S18"	0.4	58,452	2699	89.21
	A15%-S15"	0.4	65,830	2786	90.96
	A15%-S15"	0.6	40,804	2585	89.21
	A15%-S12"	0.6	43,412	2674	91.45
B. 800 Grain Total Charge - 343 grains granular and 457 grains pelleted					
A15%-S21"	A15%-S21"	0.4	32,450	2628	89.25
	A15%-S18"	0.4	39,257	2750	90.79
	A15%-S15"	0.4	54,577	2866	90.63
	A15%-S15"	0.5	39,304	2748	90.56
	A15%-S12"	0.5	55,942	2856	90.05
	A15%-S12"	0.6	41,839	2747	89.38
A15%-S12"	A15%-S21"	0.4	65,744	2719	84.14
	A15%-S18"	0.4	68,298	2831	87.22
	A15%-S15"	0.4	72,129	2936	89.91
	A15%-S12"	0.4	78,378	3025	91.85
	A15%-S21"	0.5	54,370	2503	79.18
	A15%-S18"	0.5	54,370	2617	82.80
	A15%-S15"	0.5	54,370	2738	86.62
	A15%-S12"	0.5	54,370	2849	90.13
	A15%-S15"	0.6	54,370	2540	80.33
	A15%-S12"	0.6	54,370	2671	84.48

Charge weight variations and changes in granular to pelleted propellant ratios were next more extensively investigated with the A15%-S21"/A15%-S15" granular/pelleted propellant combinations as shown in Table B-11. Again the data has been condensed for simplicity.

These computations show that ignition delay is still the most critical factor and that changes in total charge weight have no significant effect on efficiency. Changes in granular to pelleted propellant ratios also do not appear to be critical within a constant total charge weight, a factor which could be significant in developing manufacturing loading techniques.

TABLE B-11

EFFECT OF CHARGE WEIGHT VARIATIONS

Bore Resistance: RL1 (1.0" free run)

Total Charge Weight (grains)	Ignition Delay (ms)	Maximum Pressure (psi)	Muzzle Velocity (fps)	MVEL (%)
A. A15%-S21" Granular Propellant - 3 parts; A15%-S15" Pelleted Propellant - 4 parts				
630	0.3	40,935	2511	90.01
653.3	0.3	45,077	2578	90.13
		40,026	2540	90.04
700	0.3	54,348	2711	90.33
	0.4	46,163	2659	90.27
	0.5	38,254	2593	90.12
746.7	0.3	64,754	2840	90.48
	0.4	51,551	2767	90.45
	0.5	40,286	2679	90.34
770	0.4	53,536	2815	90.15
	0.5	40,563	2714	90.42
B. A15%-S21" Granular Propellant - 2 parts; A15%-S15" Pelleted Propellant - 3 parts				
675	0.3	50,817	2651	90.26
	0.4	44,461	2609	90.20
	0.5	38,050	2554	90.04
700	0.3	56,279	2722	90.36
	0.4	48,102	2673	90.29
	0.5	40,135	2609	90.13
750	0.3	68,252	2862	90.51
	0.4	54,586	2791	90.47
	0.5	42,888	2705	90.31
800	0.4	58,271	2888	90.61
	0.5	42,706	2773	90.49
825	0.4	57,918	2923	90.70
	0.5	41,262	2793	90.59
C. A15%-S21" Granular Propellant - 3 parts; A15%-S15" Pelleted Propellant - 5 parts				
720	0.3	62,845	2789	90.46
	0.4	53,004	2735	90.37
	0.5	43,434	2666	90.23
746.7	0.4	56,865	2799	90.45
	0.5	45,123	2718	90.29
800	0.4	61,845	2908	90.60
	0.5	45,598	2796	90.45
853.3	0.4	59,716	2975	90.77
	0.5	41,592	2831	90.63
880	0.4	55,201	2983	90.87
	0.5	38,046	2827	90.77

A final series of calculations was made extending the range of free run variations and reexamining the effects of changes in bore resistance. As shown in Table B-12, the effect of doubling bore resistance is to decrease ballistic efficiency, but the degree of change in ballistic efficiency appears to be essentially the same for both the standard and free run barrels. As shown in Table B-13, there is little change in ballistic efficiency or in velocity at a given peak pressure level if bore resistance is kept constant as the free run is varied.

TABLE B-12

EFFECT OF BORE RESISTANCE

A15%-S21" GRANULAR PROPELLANT 300 GRAINS

A15%-S15" PELLETED PROPELLANT 450 GRAINS

Free Run (in)	Bore Resistance	Ignition Delay (ms)	Maximum Pressure (psi)	Muzzle Velocity (fps)	MVEL (%)
0	RL0	0.5	62,711	2841	90.67
		0.6	45,011	2735	90.74
0	RH0	0.6	61,751	2772	88.60
		0.7	44,818	2668	88.50
2.0	RL2	0.4	52,956	2783	90.52
		0.5	40,663	2689	90.41
2.0	RH2	0.4	53,400	2713	88.17
		0.5	41,843	2623	87.87

TABLE B-13

EFFECT OF FREE RUN

A15%-S21" GRANULAR PROPELLANT 300 GRAINS

A15%-S15" PELLETED PROPELLANT 450 GRAINS

Free Run (in)	Bore Resistance	Ignition Delay (ms)	Maximum Pressure (psi)	Muzzle Velocity (fps)	MVEL (%)
0	RL0	0.5	62,711	2841	90.67
		0.6	45,011	2735	90.74
0.5	RL.5	0.4	57,155	2805	90.43
		0.5	46,061	2729	90.27
		0.6	37,343	2649	90.09
1.0	RL1	0.4	54,586	2791	90.47
		0.5	42,888	2705	90.31
2.0	RL2	0.4	52,956	2783	90.52
		0.5	40,663	2689	90.41
4.0	RL4	0.4	52,540	2779	90.48
		0.5	39,594	2681	90.46

REFERENCES

Ref. 1 - D. W. Riefler (Olin Corporation), "The Winchester Interior Ballistics Computer Model," WGR-72-221

Ref. 2 - A. H. Paul and D. W. Riefler (Olin Corporation), "The Winchester Group Research Interior Ballistics Program," WGR-72-227.

APPENDIX C

LOG OF BALLISTIC TEST FIRINGS

The following Table lists the individual rounds prepared and test fired in the subject contract. The test barrels used in the test firings were varied as follows:

Rounds	1 - 142	Bbl. #1	- Bore diameter out of specification
Rounds	143 - 235	Bbl. #2	- ½" free run
	236 - 339	"	- 1" " "
	340 - 457	"	- 2" " "
	458 - 471	"	3" " "
Rounds	472 - 521	Bbl. #3	- No Free Run
	522 - 530	"	- 1" " "
	531 - 575	"	- 2" " "

Velocities recorded at 25 feet.

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. nominal	Pressure psi	Velocity fps	A. T. ms
1	400 Series BALL	525 gr.	-	-	-	-	525	-	2155	7.34
2	" " "	550	-	-	-	-	550	-	-	-
3	" " "	575	-	-	-	-	575	-	-	-
4	WC 870	525	-	-	-	-	525	-	-	-
5	" "	550	-	-	-	-	550	-	-	-
6	" "	575	-	-	-	-	575	-	-	-
7	400 Series BALL	525	-	-	-	-	525	4,900	1765	-
8	" " "	550	-	-	-	-	550	17,900	2026	3.78
9	" " "	575	-	-	-	-	575	24,600	2196	3.09
10	WC 870	525	-	-	-	-	525	1,900	1147	-
11	" "	550	-	-	-	-	550	6,200	1306	-
12	" "	575	-	-	-	-	575	8,800	1401	-
13	400 Series BALL	600	-	-	-	-	600	35,400	2371	2.64
14	" " "	605	-	-	-	-	605	33,300	2347	2.74
15	" " "	600	-	-	-	-	600	30,000	2325	2.93
16	WC 870	600	-	-	-	-	600	9,200	1518	4.00
17	" "	605	-	-	-	-	605	7,100	1374	4.60
18	400 Series BALL	620	-	-	-	-	620	32,200	2398	3.15
19	" " "	620	-	-	-	-	620	29,400	2383	3.29
20	" " "	620	-	-	-	-	620	27,500	2353	3.44
21	400 Series BALL	350	400 Series BALL	-	-	270.8	625	30,200	2368	3.03
22	" " "	350	" " "	-	-	270.5	625	23,000	2220	3.53
23	" " "	300	" " "	-	-	320.8	625	21,600	2195	3.66
24	" " "	300	" " "	-	-	320.7	625	19,900	2152	3.75
25	" " "	350	" " "	-	-	303.8	650	29,100	2380	3.25
26	" " "	350	" " "	-	-	302.3	650	34,500	2437	2.97
27	" " "	350	" " "	-	-	303.0	650	44,100	2559	2.48
28	" " "	350	" " "	-	-	303.7	650	-	-	-
29	" " "	300	" " "	-	-	320.9	625	27,000	2299	-
30	" " "	300	" " "	-	-	321.9	625	25,300	2253	3.61
31	400 Series BALL	350	400 Series BALL	Spray B66		304.9	650	33,400	2477	2.81
32	" " "	350	" " "	"		303.6	650	21,000	2153	4.13
33	" " "	300	" " "	"		346.8	650	23,100	2242	3.85

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
34	" " "	300	" " "	"		345.3	650	22,100	2224	3.82
35	400 Series BALL	620	-	-	-	-	620	31,000	2432	3.12
36	" " "	620	-	-	-	-	620	27,000	2370	3.41
37	" " "	620	-	-	-	-	620	28,000	2379	3.24
38	400 Series BALL	350	400 Series BALL	-	-	303.0	650	33,500	2484	2.99
39	" " "	350	" " "	-	-	300.7	650	36,700	2526	2.62
40	" " "	350	" " "	-	-	300.0	650	36,500	2512	2.70
41	" " "	300	" " "	-	-	357.9	650	37,000	2535	2.74
42	" " "	300	" " "	-	-	355.2	650	20,000	2445	3.06
43	" " "	300	" " "	-	-	375.6	650	32,00	2492	2.88
44	400 Series BALL	350	400 Series BALL	Spray B66		307.1	650	29,000	2412	3.13
45	" " "	350	" " "	"		305.0	650	27,000	2393	3.07
46	" " "	300	" " "	"		304.7	600	24,500	2330	3.38
47	400 Series BALL	300	400 Series BALL	-	-	306.2	600	29,000	2370	2.85
48	" " "	300	" " "	-	-	307.5	600	29,000	2371	2.90
49	" " "	300	" " "	-	-	305.7	600	28,000	2347	3.06
50	400 Series BALL	620	-	-	-	-	620	29,000	2398	3.09
51	" " "	620	-	-	-	-	620	28,000	2368	3.54
52	" " "	620	-	-	-	-	620	31,000	2426	3.24
53	400 Series BALL	300	400 Series BALL	Spray B66		308.5	600	26,000	2242	3.70
54	" " "	300	" " "	"		299.7	600	14,000	2003	6.65
55	" " "	300	" " "	"		305.2	600	11,000	1891	5.39
56	" " "	300	" " "	"		349.5	650	26,000	2334	3.29
57	" " "	300	" " "	"		355.2	650	20,000	2227	3.98
58	" " "	300	" " "	"		354.9	650	-	-	-
59	" " "	300	" " "	"		368.8	675	26,000	2353	3.69
60	" " "	300	" " "	"		357.3	675	27,500	2381	3.49
61	" " "	300	" " "	"		374.7	675	26,000	2343	3.55
62	400 Series BALL	300	400 Series BALL	Spray B66	.45%	349.4	650	28,200	2298	4.90
63	" " "	300	" " "	"	"	352.5	650	30,900	2381	3.27
64	" " "	300	" " "	"	"	352.4	650	30,600	2387	3.15

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
65	400 Series BALL	300	400 Series BALL	Spray B66	.60%	351.8	650	36,800	2434	2.79
66	" " "	300	" " "	"	"	350.2	650	40,500	2512	2.64
67	" " "	300	" " "	"	"	354.1	650	42,200	2547	2.54
68	400 Series BALL	300	WC844	Spray B66	.55%	349.5	650	38,000	2521	2.83
69	" " "	300	"	"	"	355.1	650	36,900	2502	3.04
70	" " "	300	"	"	"	356.8	650	38,400	2525	3.06
71	400 Series BALL	620	-	-	-	-	620	-	2346	-
72	" " "	620	-	-	-	-	620	31,200	2378	3.28
73	" " "	620	-	-	-	-	620	30,300	2370	3.37
74	400 Series BALL	300	400 Series BALL Small, Nitrate	Spray B66	.8%	350.1	650	41,400	2576	2.58
75	" " "	300	" " "	"	"	349.6	650	34,700	2481	2.87
76	" " "	300	" " "	"	"	350.2	650	34,100	2484	2.80
77	400 Series BALL	300	WC844 Small	Spray B66	.7%	350.3	650	42,000	2577	2.86
78	" " "	300	" "	"	"	350.7	650	44,000	2607	-
79	" " "	300	" "	"	"	351.3	650	43,200	2599	2.56
80	" " "	620	-	-	-	-	620	27,700	2310	3.38
81	" " "	620	-	-	-	-	620	26,400	2357	3.45
82	" " "	620	-	-	-	-	620	31,400	2421	3.15
83	400 Series BALL	300	400 Series BALL	Spray B66	.8%	340.0	650	32,400	2464	2.96
84	" " "	300	" " "	"	"	351.5	650	29,600	2344	3.24
85	" " "	300	" " "	"	"	375.0	675	34,500	2516	3.24
86	" " "	300	" " "	"	"	374.6	675	35,700	2528	2.91
87	" " "	300	" " "	"	"	375.0	675	35,800	2519	3.33
88	" " "	300	" " "	"	"	401.0	700	41,100	2666	2.66
89	" " "	300	" " "	"	"	400.9	700	39,100	2609	2.73
90	" " "	300	" " "	"	"	400.3	700	36,100	2588	2.79
91	400 Series BALL	300	400 Series BALL Small, w/Nitrate	Spray B66	.8%	375.5	675	41,100	2588	2.59

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A.T. ms
92	" " "	300	" " "	"	"	375.4	675	35,400	2535	2.79
93	" " "	300	" " "	"	"	376.0	675	36,700	2552	2.81
94	400 Series BALL	620	-	-	-	-	620	30,000	2339	-
95	" " "	620	-	-	-	-	620	24,600	2316	3.64
96	" " "	620	-	-	-	-	620	31,300	2411	3.22
97	400 Series BALL	300	400 Series BALL Nitrate, Small	Spray B66	.85%	375.7	675	33,700	2509	2.86
98	" " "	300	" " "	"	"	375.0	675	34,800	2518	2.37
99	" " "	300	" " "	"	"	375.0	675	32,900	2486	2.94
100	400 Series BALL	300	WC844 Small	Spray B66	.66%	349.9	650	44,400	2599	2.57
101	" " "	300	" "	"	"	350.3	650	42,200	2579	2.60
102	" " "	300	" "	"	"	350.9	650	42,000	2620	2.53
103	400 Series BALL	300	400 Series BALL	Spray B66	.77%	399.6	700	34,000	2556	2.93
104	" " "	300	" " "	"	"	401.2	700	33,000	-	2.94
105	" " "	300	" " "	"	"	400.7	700	34,000	2579	2.80
106	400 Series BALL	620	-	-	-	-	620	26,000	2347	3.52
107	" " "	620	-	-	-	-	620	32,500	2432	3.27
108	" " "	620	-	-	-	-	620	31,100	2396	3.40
109	" " "	620	-	-	-	-	620	29,010	-	-
110	" " "	620	-	-	-	-	620	27,000	-	3.36
111	" " "	620	-	-	-	-	620	-	-	3.60
112	400 Series BALL	300	400 Series BALL Nitrate	Spray B66	.85%	401.0	700	32,000	2512	2.83
113	" " "	300	" " "	"	"	400.7	700	32,800	2513	2.88
114	" " "	300	" " "	"	"	400.7	700	33,200	2513	2.80
115	400 Series BALL	300	400 Series BALL Nitrate, Small	Spray B66	.94%	399.9	700	26,900	2367	.3.56
116	" " "	300	" " "	"	"	400.0	700	29,500	2448	3.30
117	" " "	300	" " "	"	"	400.6	700	29,500	2186	2.27
118	400 Series BALL	300	400 Series BALL	Spray	1.40%	400.3	700	16,000	2125	4.95
119	" " "	300	Nitrate, Small	B66	"	400.9	700	24,800	2327	2.97
120	" " "	300	" " "	"	"	400.7	700	24,500	2296	3.42

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
121	400 Series BALL	300	400 Series BALL Small	Spray B66	.77%	425.5	725	31,100	2503	3.21
122	" " "	300			"	425.0	725	32,500	2220	1.80
123	" " "	300	" " "	"	"	424.0	725	33,000	2509	2.97
124	400 Series BALL	300	WC844, Small	Spray	1.09%	350.0	650	38,500	2262	1.80
125	" " "	300	" "	B66	"	351.0	650	37,000	2513	2.72
126	" " "	300	" "	"	"	350.9	650	34,500	2418	2.73
127	400 Series BALL	300	WC844, Small	Spray	1.72%	349.8	650	34,200	-	-
128	" " "	300	" "	B66	"	350.6	650	31,800	2436	2.90
129	" " "	300	" "	"	"	350.8	650	29.900	-	1.96
130	400 Series BALL	300	WC844, Small	Spray	1.09%	375.0	675	42,500	2601	2.08
131	" " "	300	" "	B66	"	376.0	675	40,000	2367	1.81
132	" " "	300	" "	"	"	375.8	675	40,000	2577	2.50
133	400 Series BALL	300	WC844, Small	Spray	1.72%	374.9	675	34,500	2301	2.13
134	" " "	300	" "	B66	"	375.9	675	34,000	-	2.73
135	" " "	300	" "	"	"	374.8	675	31,800	2494	2.94
136	400 Series BALL	300	400 Series BALL Nitrate, Small	Spray B66	.85%	425.4	725	31,200	2482	-
137	" " "	300	" "	"	"	424.3	725	35,200	2482	1.92
138	" " "	300	" "	"	"	425.6	725	33,300	2521	1.43
139	400 Series BALL	300	WC844, Small	Spray	1.09%	400.0	700	36,800	2534	2.10
140	" " "	300	" "	B66	"	400.4	700	39,500	2574	1.68
141	" " "	300	" "	"	"	425.0	725	45,000	2658	-
142	400 Series BALL	300	WC844, Small	Spray B66	1.72%	400.3	700	31,500	2456	-
143	400 Series BALL	300	400 Series BALL	Spray	.45%	296.5	600	15,200	2114	4.25
144	" " "	300	" " "	B66	"	304.0	600	13,500	2019	4.77
145	" " "	300	" " "	"	"	327.7	625	24,500	2312	3.53
146	" " "	300	" " "	"	"	327.5	625	20,300	2238	3.89
147	" " "	300	" " "	"	"	352.3	650	15,200	2157	4.51
148	" " "	300	" " "	"	"	352.5	650	26,100	2372	3.48
149	" " "	300	" " "	"	"	376.4	675	29,400	2455	3.40
150	" " "	300	" " "	"	"	376.4	675	23,200	2371	3.82
151	400 Series BALL	300	400 Series BALL	Spray	.60%	304.6	600	24,500	2284	3.21

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
152	" " "	300	" " "	B66	"	304.4	600	14,600	2074	4.60
153	" " "	300	" " "	"	"	329.5	625	27,600	2372	3.12
154	" " "	300	" " "	"	"	327.6	625	27,800	2272	3.14
155	400 Series BALL	300	WC844	Spray	.55%	306.2	600	29,700	2375	2.92
156	" " "	300	"	B66	"	302.2	600	27,400	4157	5.31
157	" " "	300	"	"	"	332.7	625	31,400	3956	3.16
158	" " "	300	"	"	"	332.5	625	30,000	2438	3.02
159	400 Series BALL	620	-	-	-	-	620	31,100	2447	2.33
160	" " "	620	-	-	-	-	620	31,800	2455	2.75
161	" " "	620	-	-	-	-	620	30,800	2443	3.37
162	400 Series BALL	300	400 Series BALL	Spray	.60%	353.7	650	25,300	2350	3.83
163	" " "	300	" " "	B66	"	353.6	650	21,400	2230	3.37
164	" " "	300	" " "	"	"	370.5	675	32,200	2401	2.51
165	" " "	300	" " "	"	"	377.5	675	29,600	2315	2.15
166	" " "	300	" " "	"	"	402.7	700	41,000	-	-
167	" " "	300	" " "	"	"	403.5	700	35,600	2570	2.09
168	400 Series BALL	300	WC844	Spray	.55%	354.8	650	32,500	2473	2.99
169	" " "	300	"	B66	"	355.0	650	30,500	2451	2.66
170	" " "	300	"	"	"	378.4	675	37,300	2577	2.21
171	" " "	300	"	"	"	374.0	675	35,900	2549	2.09
172	" " "	300	"	"	"	403.3	700	41,200	2657	2.11
173	" " "	300	"	"	"	403.8	700	39,900	2578	3.05
174	400 Series BALL	300	WC844	-	-	277.0	575	30,200	2359	2.17
175	" " "	300	"	-	-	276.0	575	29,300	2341	2.17
176	" " "	300	"	-	-	305.4	600	35,800	2472	2.10
177	" " "	300	"	-	-	305.6	600	38,500	2481	2.13
178	400 Series BALL	600	-	-	-	-	600	35,200	2499	2.60
179	" " "	620	-	-	-	-	620	37,900	2550	2.10
180	" " "	640	-	-	-	-	640	43,400	2661	2.03
181	" " "	640	-	-	-	-	640	-	-	-
182	400 Series BALL	300	WC844	-	-	323.2	625	40,500	2483	2.16
183	" " "	300	"	-	-	350.0	650	79,700	2-43	2.05
184	" " "	300	"	-	-	377.9	675	-	-	-

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A.T. ms
349	WC 748	640	-	-	-	-	640	44,100	2584	3.13
350	"	640	-	-	-	-	640	44,200	2601	3.00
351	"	650	-	-	-	-	650	46,200	2626	3.02
352	"	650	-	-	-	-	650	45,100	2624	3.04
353	WC 844	300	WC 680 Washed	Dipped B66	1.9%	303.8	600	34,700	2441	2.99
354	"	300	" "	"	"	350.0	650	34,700	2507	3.02
355	"	300	" "	"	"	401.6	700	34,900	2579	3.16
356	400 Series BALL	300	Reference Blend			452.4	750	47,200	2732	2.64
357	" " "	300	" "			453.3	750	50,100	2751	2.52
358	" " "	300	" "			454.0	750	44,700	2703	2.64
359	WC 844	650	-	-	-	-	650	43,500	2603	2.72
360	"	650	-	-	-	-	650	46,800	2595	2.18
361	"	650	-	-	-	-	650	40,000	2588	2.82
362	400 Series BALL	300	Reference Blend			474.0	775	49,100	2778	2.50
363	" " "	300	" "			472.0	775	54,000	2705	1.73
364	WC 844	300	" "			452.0	750	54,000	2669	1.63
365	"	300	" "			449.7	750	60,200	2226	1.45
366	WC 844	300	WC 844 w/10% undet.(.010")	Dipped NC, B66		475.9	775	42,500	2640	2.77
367	"	300	"	"		477.4	775	43,500	2635	2.57
368	WC 844	300	WC 680 Washed	Dipped B66	1.9%	427.4	725	41,900	2695	-
369	"	300	" "	"	"	451.7	750	46,200	2772	2.56
370	"	300	" "	"	"	473.0	775	52,700	2847	2.64
371	"	300	" "	"	"	473.6	775	58,800	2876	2.36
372	"	300	" "	"	"	473.2	775	52,100	2850	2.70
373	"	340	" "	"	"	472.2	815	71,300	2880	1.72
374	"	340	" "	"	"	479.0	815	-	-	-
375	WC 844	340	WC 844	Dipped NC, B66	1.60%	473.9	815	45,400	2706	2.62
376	"	340	"	"	"	478.9	815	47,800	2727	2.63
377	400 Series BALL	300	WC 844	-	-	321.7	625	43,800	2508	2.28

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
378	" " "	300	"	-	-	354.6	650	42,600	2571	-
379	" " "	300	"	-	-	378.9	675	46,300	2632	2.65
380	WC 844	300	400 Series BALL	-	-	325.0	625	61,500	2578	1.60
381	"	300	" " "	-	-	299.0	600	51,700	2427	1.60
382	"	300	" " "	-	-	328.8	625	56,900	2492	1.52
383	400 Series BALL	300	400 Series BALL	-	-	346.4	650	32,500	2436	3.07
384	" " "	300	" " "	-	-	376.8	675	3-,500	2541	2.78
385	" " "	300	" " "	-	-	403.1	700	42,400	2625	2.63
386	400 Series BALL	300	WC 680 Washed	Dipped B66	1.9%	477.8	775	31,900	2609	3.00
387	" " "	300	" "	"		475.8	775	31,800	2595	3.08
388	WC 844	585	WC 844	Dipped NC, B66		67.3	650	44,600	2582	2.55
389	"	585	"	"		66.1	650	43,700	2582	2.50
390	"	520	"	"		134.0	650	39,000	2519	2.67
391	"	520	"	"		132.1	650	42,400	2543	2.58
392	"	450	"	"		199.0	650	34,700	2425	2.77
393	"	450	"	"		200.0	650	37,800	2472	2.68
394	"	385	"	"		265.4	650	31,800	2375	2.87
395	"	310	"	"		346.0	650	31,500	2399	2.96
396	WC 844	300	WC 844	Dipped NC, B66		478.0	775	56,300	2153	1.80
397	"	300	"	"		472.6	775	44,800	2622	2.50
398	WC 844	640	WC 844	Dipped NC, B66		66.4	700	51,700	2697	2.37
399	"	587	"	"		139.5	730	50,600	2706	2.43
400	"	534	"	"		206.6	740	50,100	2680	2.38
401	"	484	"	"		265.4	750	48,400	2660	2.47
402	"	441	"	"		326.7	765	52,300	2684	2.40
403	"	424	"	"		382.3	800	61,800	2784	1.80
404	WC 844	330	WC 680 Washed	Dipped B66	1.9%	454.5	780	73,700	1927	1.31
405	"	399	" "	"	"	407.0	800	70,300	1949	1.66
406	"	429	" "	"	"	353.6	780	-	-	-

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
407	WC 680	500	-	-	-	-	500	60,900	1933	2.09
408	"	525	-	-	-	-	525	-	-	-
409	"	550	-	-	-	-	550	-	-	-
410	WC 844	485	WC 844 w/10% undet.	Dipped NC, B66		262.3	745	45,400	2669	2.51
411	"	485	"	"		259.8	745	50,500	2741	2.47
412	"	555	"	"		205.0	760	51,300	2721	2.50
413	"	555	"	"		211.8	760	50,800	2731	2.48
414	400 Series BALL	430	WC 844 w/10% undet.	Dipped NC, B66		261.7	690	20,600	2265	3.58
415	" " "	430	"	"		262.2	690	15,800	2111	7.87
416	" " "	485	"	"		211.6	690	-	-	-
417	" " "	485	"	"		210.0	690	-	-	-
418	WC 844	300	WC 680 Washed	Dipped B66	1.9%	303.0	*600	15,500	2050	4.89
419	"	300	" "	"	"	400.0	*700	23,100	2339	4.92
420	"	300	" "	"	"	455.5	*750	22,800	2393	-
421	2/3 WC 844 1/3 400 Series B	300	WC 680 Washed	Dipped B66	1.9%	476.7	775	46,100	2761	-
422	"		" "	"	"	476.5	775	45,700	2762	-
423	1/3 WC 844 2/3 400 Series B	300	WC 680 Washed	Dipped B66	1.9%	469.4	775	37,400	2661	2.97
424	"		" "	"	"	474.8	775	40,000	2697	-
425	400 Series BALL	300	WC 844	-	-	325.6	625	43,700	2375	2.66
426	" " "	300	"	-	-	331.5	625	43,400	-	2.68
427	400 Series BALL	300	400 Series BALL			322.3	625	34,600	2442	2.81
428	" " "	300	" " "			326.3	625	40,600	2508	2.66
429	" " "	300	" " "			302.0	600	60,200	2525	1.63
430	" " "	300	" " "			301.0	600	59,400	2602	2.37
431	WC 844-Pellets Crushed-Used As Granular	600	-	-	-	-	600	48,100	-	-
432	"	600	-	-	-	-	600	50,400	2513	2.20

*Short Base Projectiles

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
185	400 Series BALL	300	WC844	Spray B66	.55%	443.4	750	50,000	2778	1.88
186	" " "	300	"	"	"	449.9	750	58,300	2749	2.09
187	400 Series BALL	650	-	-	-	-	650	40,900	-	-
188	" " "	650	-	-	-	-	650	47,300	2687	2.07
189	" " "	660	-	-	-	-	660	-	2686	2.07
190	" " "	660	-	-	-	-	660	-	-	-
191	400 Series BALL	300	400 Series BALL	Dipped NC, B66	2.5%	433.0	730	24,100	2246	4.61
192	" " "	300	" " "	"	"	432.1	730	26,000	-	-
193	WC 760	600	-	-	-	-	600	44,800	2293	2.94
194	"	600	-	-	-	-	600	-	-	-
195	"	650	-	-	-	-	650	34,300	2405	2.81
196	"	650	-	-	-	-	650	34,600	2410	2.79
197	400 Series BALL	300	400 Series BALL	Dipped NC, B66	2.5%	446.0	750	32,300	2516	-
198	" " "	300	" " "	"	"	440.9	750	26,000	2422	2.70
199	WC 870 Rolled	300	WC844	Spray B66	.55%	471.0	775	54,000	2770	2.09
200	" "	300	"		"	475.0	775	54,000	2785	-
201	" "	300	"	"	"	477.4	775	60,400	2824	-
202	WC 870 Rolled	300	WC844	Spray	.60%	448.8	750	54,400	2754	2.21
203	" "	300	"	"	"	449.8	750	59,100	2781	2.33
204	400 Series BALL	300				451.7	750	58,200	2825	
205	" " "	300				446.7	750	59,200	2835	
206	400 Series BALL	300	400 Series BALL	Dipped NC, B66	2.5%	484.8	785	40,000	2687	
207	WC 844 w/5% un-det.	550	-	-	-	-	550	40,100	2404	4.02
208	" " "	575	-	-	-	-	575	51,800	2529	4.15
209	" " "	600	-	-	-	-	600	-	-	-
210	" " "	600	-	-	-	-	600	-	-	-
211	400 Series BALL	300	WC844	Spray B66	1.05%	542.4	750	54,600	2805	2.27

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A.T. ms
212	" " "	300	"	"	"	450.6	750	52,100	2793	2.27
213	" " "	300	"	"	"	476.6	775	-	-	-
214	" " "	300	"	"	"	476.9	775	-	-	-
215	WC870 Rolled	300	WC844	Spray	1.05%	475.1	775	54,600	2806	
216	" "	300	"	B66	"	473.4	775	54,600	2809	2.15
217	" "	300	"	"	"	474.3	775	56,300	2821	3.36
218	WC749	600	-	-	-	-	600	32,300	2350	4.03
219	"	620	-	-	-	-	620	35,400	2456	3.60
220	"	640	-	-	-	-	640	-	-	-
221	"	640	-	-	-	-	640	41,800	2496	3.19
222	"	640	-	-	-	-	640	42,200	2546	3.14
223	"	650	-	-	-	-	650	-	2521	3.61
224	400 Series BALL	300	Reference Blend	Spray	-	426.9	725	48,100	2660	3.51
225	" " "	300	" "	B66	-	425.9	725	47,100	2671	2.64
226	" " "	300	" "	"	-	421.6	725	49,600	2658	2.49
227	" " "	300	" "	"	-	453.0	750	52,600	2747	2.43
228	" " "	300	" "	"	-	451.1	750	56,200	2781	2.32
229	" " "	300	" "	"	-	452.2	750	48,500	2694	2.50
230	WC749	660	-	-	-	-	660	45,500	2609	3.10
231	WC740	620	-	-	-	-	620	41,300	2491	3.97
232	"	640	-	-	-	-	640	38,400	2512	3.48
233	"	640	-	-	-	-	640	45,900	2571	3.28
234	"	650	-	-	-	-	650	49,300	2616	2.96
235	"	660	-	-	-	-	660	48,600	2632	3.99
236	WC 740	650	-	-	-	-	650	47,900	2577	3.09
237	"	650	-	-	-	-	650	33,900	2451	4.71
238	"	650	-	-	-	-	650	45,400	2558	3.15
239	"	660	-	-	-	-	650	47,200	2582	3.30
240	"	660	-	-	-	-	660	40,800	2539	3.36
241	"	660	-	-	-	-	660	46,000	2582	-
242	400 Series BALL	300	Reference Blend	Spray		452.8	750	52,800	2645	2.51
243	" " "	300	" "	B66	-	452.0	750	54,700	2682	2.34
244	" " "	300	" "	"	-	450.0	750	54,800	2702	3.37
245	WC 748	640	-	-	-	-	640	55,300	2692	2.82

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
246	"	650	-	-	-	-	650	-	-	-
247	"	660	-	-	-	-	660	-	-	-
248	400 Series BALL	300	WC 844	Spray B66	1.19%	454.0	750	47,000	2639	3.58
249	" " "	300	"	"	"	455.0	750	51,400	2703	2.70
250	" " "	300	"	"	"	470.1	775	51,300	2708	-
251	" " "	300	"	"	"	469.0	755	-	-	-
252	400 Series BALL	300	WC 844	Dipped, NC, B66	3.60%	450.8	750	-	-	-
253	" " "	300	"	"	"	448.2	750	34,000	2466	-
254	" " "	300	"	"	"	476.1	775	31,700	2447	3.12
255	" " "	300	"	"	"	477.1	775	31,800	2447	3.97
256	400 Series BALL	300	WC 844 w/10% undet.	Dipped B66		424.5	725	52,300	2695	3.46
257	" " "	300	"	"		424.8	725	50,900	2635	3.46
258	" " "	300	"	"		449.2	750	56,800	2750	3.37
259	" " "	300	"	"		450.5	750	57,600	2776	3.33
260	400 Series BALL	300	WC 844	Spray B66	1.05%	456.5	750	49,800	2727	3.49
261	" " "	300	"	"	"	451.8	750	52,600	2737	3.40
262	WC 748	600	-	-	-	-	640	51,100	2607	3.76
263	"	640	-	-	-	-	640	-	-	-
264	WC 749	650	-	-	-	-	650	32,100	2506	-
265	"	650	-	-	-	-	650	38,500	2552	-
266	"	650	-	-	-	-	650	37,100	2556	-
267	WC 844	640	-	-	-	-	640	43,400	2599	-
268	"	640	-	-	-	-	640	37,600	2541	-
269	"	650	-	-	-	-	650	33,900	2517	-
270	"	650	-	-	-	-	650	46,500	2633	-
271	WC 844	300	WC 844	Dipped NC, B66	3.60%	481.7	775	37,300	2600	-
272	"	300	"	"	"	481.9	775	37,900	2592	-
273	"	300	"	"	"	477.7	775	39,500	2618	-

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
274	400 Series BALL	270	WC 844	Spray B66	1.19%	473.8	745	44,400	2699	-
275	" " "	270	"	"	"	478.4	745	39,000	2652	
276	400 Series BALL	270	WC 844 w/10% undet.	Dipped NC, B66	"	476.2	745	26,400	2413	-
277	" " "	270	"	"		476.5	745	27,400	2438	-
278	400 Series BALL	270	Reference Blend			449.9	720	-	-	-
279	" " "	270	" "			451.4	720	55,700	2779	-
280	" " "	270	" "			457.4	720	40,300	-	-
281	WC 844	340	WC 844 w/10% undet	Dipped NC, B66		472.7	815	39,200	2660	2.31
282	"	340	"	"		478.2	815	39,300	2672	1.98
283	400 Series BALL	300	WC 844 w/10% undet. (.010")	Dipped NC, B66		478.8	775	29,600	2471	3.13
284	" " "	300	"	"		480.9	775	25,400	2393	2.05
285	400 Series BALL	300	WC 844 2/25% undet.	Dipped NC, B66		475.4	775	26,000	2372	1.60
286	" " "	300	"	"		476.3	775	26,800	2391	1.97
287	WC 844	650	-	-	-	-	650	40,600	2619	-
288	"	650	-	-	-	-	650	36,400	2566	3.40
289	"	650	-	-	-	-	650	45,100	2626	2.89
290	WC 844	300	WC 844 w/10% undet.	Dipped NC, B66		476.2	815	41,400	2731	2.00
291	"	340	"	"		475.9	815	-	2730	-
292	400 Sereis BALL	300	WC 844 w/25% undet.	Dipped NC, B66		475.6	775	30,400	2468	3.43
293	" " "	300	"	"		474.8	775	29,800	2440	1.57
294	400 Series BALL	300	WC 844	-		325.4	625	49,000	2550	1.73
295	" " "	300	"	-		357.7	650	52,100	2621	3.71
296	" " "	300	"	-		377.0	675	58,800	2669	2.74
297	WC 844	300	WC 844	-	-	325.9	625	63,400	2652	2.24
298	"	300	"	-	-	353.2	650	-	-	-

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
299	"	300	"	-	-	375.3	675	-	-	-
300	400 Series BALL	300	WC 844 w/10% undet.	Dipped NC, B66		477.4	775	29,400	2482	3.15
301	" " "	300	"	"		474.1	775	-	2517	1.99
302	400 Series BALL	300	WC 844 w/10% undet. (.010"R)	Dipped NC, B66		474.9	775	31,700	2494	2.96
303	" " "	300	"	"		476.9	775	27,800	2437	3.51
304	400 Series BALL	300	WC 844 w/25% undet.	Dipped NC. B66		476.6	775	33,900	2537	2.97
305	" " "	300	"	"		475.8	775	33,800	2527	2.96
306	WC 844	340	WC 844 w/10% undet.	Dipped NC, B66		471.7	815	50,300	2773	1.97
307	"	340	"	"		472.0	815	52,500	2800	2.38
308	WC 844	340	WC 844 undet.	Dipped NC, B66		475.7	815	55,100	2793	2.92
309	"	340	"	"		471.4	815	57,100	2808	-
310	WC 844	340	WC 844 w/25% undet.	Dipped NC, B66		469.7	815	52,400	2785	-
311	"	340	"	"		472.7	815	55,600	2785	3.72
312	400 Series BALL	300	WC 844 w/25% undet.	Dipped NC, B66		406.0	700	-	-	-
313	" " "	300	"	"		432.7	730	-	-	-
314	WC 870 Rolled	300	.013"/.009"	Dipped B66		447.0	750	79,500	2859	3.79
315	" "	300	"	"		463.0	*760	51,800	2746	-
316	400 Series BALL	300	400 Series BALL	-	-	349.1	650	51,000	2695	-
317	" " "	300	" " "	-	-	376.1	675	54,300	2691	-
318	" " "	300	" " "	-	-	401.6	700	54,300	2708	3.64
319	WC 844	300	400 Series BALL	-	-	348.1	650	-	-	-
320	"	300	" " "	-	-	375.3	675	-	-	-
321	"	300	" " "	-	-	407.9	700	-	-	-
322	WC 844	640	-	-	-	-	640	41,900	2574	-

*Short Base Projectiles

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
323	"	640	-	-	-	-	640	42,500	2588	-
324	"	650	-	-	-	-	650	42,200	2599	-
325	"	650	-	-	-	-	650	48,900	2624	-
326	WC 870 Rolled	300	.013"/.009"	Dipped B66		323.3	625	34,200	2406	2.78
327	" "	300	"	"		326.0	625	44,100	2484	-
328	400 Series BALL	300	400 Series BALL	-	-	349.8	650	49,700	2592	-
329	" " "	300	" " "	-	-	376.4	675	49,900	2633	3.11
330	WC 844	300	400 Series BALL	-	-	307.8	600	51,300	2555	2.42
331	"	300	" " "	-	-	328.4	625	57,200	2544	-
332	400 Series BALL	300	WC 844 w/10% undet.	Dipped NC, B66		525.0	*825	27,600	2479	-
333	" " "	300	"	"		551.5	*850	24,200	2429	3.78
334	" " "	350	"	"		552.7	*900	33,500	2669	3.08
335	" " "	350	"	"		575.6	*925	30,700	2664	3.24
336	400 Series BALL	300	.013"/.009"	Dipped B66		323.4	625	39,800	2466	4.44
337	WC 760	650	-	-	-	-	650	29,600	2362	2.89
338	"	650	-	-	-	-	650	32,300	2393	-
339	WC 870 Rolled	300	.013"/.009"	Dipped B66		445.0	*750	48,200	2666	-

Barrel #2, 2" Free Run

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
340	WC 749	650	-	-	-	-	650	34,000	2497	-
341	"	650	-	-	-	-	650	31,800	2480	3.23
342	"	650	-	-	-	-	650	32,500	2487	3.40
343	WC 740	660	-	-	-	-	660	29,200	2466	3.69
344	"	660	-	-	-	-	660	30,100	2477	3.60
345	"	660	-	-	-	-	660	33,600	2494	3.51
346	WC 760	650	-	-	-	-	650	30,700	2381	-
347	"	650	-	-	-	-	650	-	2380	3.43
348	"	650	-	-	-	-	650	29,800	2372	3.41

*Short Base Projectiles

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
433	WC 844	300	WC 844 w/10% undet.	Dipped B66		397.4	700	16,200	2057	4.13
434	"	300	"	"		452.5	750	13,200	2024	4.06
435	"	300	"	"		471.6	775	22,900	2315	3.43
436	"	500	"	"		205.4	700	35,000	2558	3.03
437	"	500	"	"		207.9	700	37,000	-	-
438	Same as 431 & 432, screened	600						40,700	2486	2.29
439	"	600						40,900	2482	2.73
440	WC 844	330	WC 680 Washed	Dipped B66	1.9%	506.1	*835	54,300	2845	-
441	"	350	" "	"	"	529.4	*880	49,500	2828	3.17
442	"	370	" "	"	"	553.4	*925	65,400	-	2.51
443	"	395	" "	"	"	574.3	970	-	-	-
444	WC 844	600	-	-	-	-	600	45,900	2511	2.69
445	"	600	-	-	-	-	600	43,900	2510	2.81
446	2/3 WC 844 1/3 400 Series B	370	WC 680 Washed	Dipped B66	1.9%	549.8	*920	52,300	2939	2.42
447	"	395	" "	"	"	573.9	*965	66,-00	3092	-
448	1/3 WC 844 2/3 400 Series B	395	WC 680 Washed	Dipped B66	1.9%	576.0	*970	55,100	3004	2.79
449	WC 844	300	WC 660	Dipped B66		403.2	700	83,300	-	-
450	"	300	"	"		431.6	730	-	-	-
451	"	300	"	"		450.5	750	-	-	-
452	"	300	"	"		474.7	775	-	-	-
453	400 Series BALL	300	WC 660	Dipped B66		352.6	650	57,300	2541	2.25
454	" " "	300	"	"		399.4	700	57,100	2689	2.74
455	" " "	300	"	"		426.4	725	68,600	2768	2.03
456	" " "	300	"	"		499.6	*800	67,000	2878	2.66
457	" " "	300	"	"		547.3	850	-	-	-

*Short Base Projectiles

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
3" Free Run										
458	400 Series BALL	300	WC 660	Dipped B66		356.5	650	39,900	2518	2.57
459	" " "	300	"	"		401.5	700	47,700	2670	2.95
460	" " "	300	"	"		428.4	725	48,600	2723	2.53
461	2/3 WC 844, 1/3 400 Series B	395	WC 680 Washed	Dipped B66	1.9%	574.7	*970	59,900	3061	3.78
462	1/3 WC 844, 2/3 400 Series B	395	WC 680 Washed	Dipped B66	1.9%	574.4	*970	52,000	3002	-
463	WC 844	300	WC 680 Washed	Dipped	1.9%	453.1	750	40,500	-	2.84
464	"	300	" "	"	"	475.9	775	46,700	2768	2.47
465	2/3 WC 844, 1/2 400 Series B	300	WC 680 Washed	Dipped	1.9%	471.0	775	43,700	2750	2.26
466	400 Series BALL	300	400 Series BALL	-	-	397.5	700	58,700	2566	1.58
467	400 Series BALL	300	WC 844	-	-	378.7	675	56,400	2548	1.72
468	WC 844	300	WC 844	-	-	378.9	675	67,100	2579	1.56
469	WC 844	350	WC 680 Washed	Dipped B66	1.9%	529.6	*875	46,700	2846	-
470	2/3 WC 844, 1/3 400 Series B	370	WC 680 Washed	Dipped B66	1.9%	550.0	*920	49,900	2916	2.61
471	1/3 WC 844, 2/3 400 Series B	395	WC 680 Washed	Dipped B66	1.9%	570.4	*965	47,900	2939	2.99
Barrel #3, 0" Free Run										
472	400 Series BALL	650	-	-	-	-	650	42,700	2532	-
473	" " "	650	-	-	-	-	650	42,200	2519	3.23
474	WC 844	620	-	-	-	-	620	47,000	2565	2.93
475	"	620	-	-	-	-	620	46,300	2559	2.79
476	"	650	-	-	-	-	650	49,200	2631	2.69
477	"	650	-	-	-	-	650	51,000	2646	2.61
478	WC 740	620	-	-	-	-	620	63,900	2642	3.48

*Short Base Projectiles

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
479	"	620	-	-	-	-	-	64,500	2635	3.30
480	400 Series BALL	300	Reference Blend	Spray B66		424.0	725	51,600	2683	2.62
481	" " "	300	" "			448.4	750	52,200	2739	2.70
482	400 Series BALL	300	WC 844	-	-	277.2	575	46,800	2433	2.66
483	" " "	300	"	-	-	297.1	600	45,600	2466	2.69
484	" " "	300	"	-	-	323.5	625	51,400	2542	2.59
485	400 Series BALL	300	WC 844	Dipped NC B66	3.6%	275.5	575	18,800	1975	4.19
486	" " "	300	"	"	"	299.0	600	42,900	2319	3.72
487	" " "	300	"	"	"	327.5	625	27,000	2201	3.81
488	WC 844	300	WC 680 Washed	Dipped B66	1.9%	277.3	575	35,700	2367	3.18
489	"	300	" "	"	"	300.5	600	39,800	2441	2.92
490	"	300	" "	"	"	323.0	625	49,800	2563	2.58
491	WC 760	650	-	-	-	-	650	32,300	2350	2.92
492	"	650	-	-	-	-	650	25,900	2282	3.35
493	"	650	-	-	-	-	650	37,900	2422	2.74
494	400 Series BALL	300	WC 844	Dipped NC, B66	3.60%	350.5	650	46,900	2434	3.45
495	" " "	300	"	"	"	402.0	700	37,500	2429	3.28
496	" " "	300	"	"	"	421.4	725	40,900	2-91	3.09
497	WC 844	300	WC 680 Washed	Dipped B66	1.9%	352.0	650	47,000	2587	2.72
498	400 Series BALL	300	WC 844	Dipped NC, B66	3.60%	326.6	625	28,400	2217	3.45
499	WC 760	650	-	-	-	-	650	34,300	2387	2.84
500	"	650	-	-	-	-	650	35,700	2407	2.72
501	400 Series BALL	300	WC 844	-	-	326.8	625	52,300	2555	2.50
502	" " "	300	"	-	-	328.5	625	52,700	2570	2.46
503	" " "	300	"	-	-	329.5	625	52,000	2567	2.48
504	" " "	300	"	-	-	328.5	625	52,500	2563	2.47

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
505	400 Series BALL	300	Reference Blend	Spray B66		449.7	750	59,800	2798	2.33
506	" " "	300	" "	"		452.8	750	61,900	2809	2.31
507	" " "	300	" "	"		450.8	750	57,600	2779	2.41
508	400 Series BALL	300	WC 844	Dipped NC.B66	3.60%	454.2	750	39,600	2546	2.95
509	" " "		"	"	"	449.2	750	32,200	2378	-
510	WC 844	300	WC 680 Washed	Dipped B66	1.9%	376.0	675	52,100	2670	2.72
511	WC 844	300	WC 844	Dipped NC, B66	3.60%	325.3	625	30,900	2232	3.12
512	"	300	"	"	"	369.9	670	38,600	2376	2.88
513	WC 844	300	WC 680 Washed	Dipped B66	1.9%	375.1	675	51,400	2654	2.80
514	"	300	" "	"	"	374.5	675	57,300	2699	2.50
515	"	300	" "	"	"	378.7	675	55,100	2678	2.64
516	WC 844	300	WC 844	Dipped NC, B66	3.60%	400.6	700	41,500	2492	2.85
517	"	300	"	"	"	423.8	725	40,900	2486	2.85
518	"	300	"	"	"	449.6	750	42,500	2540	2.89
519	WC 844	300	WC 844	Dipped NC, B66	3.60%	474.4	775	41,900	2545	3.90
520	400 Series BALL	620	-	-	-	-	620	34,400	2403	3.01
521	" " "	620	-	-	-	-	620	-	2531	2.97
Barrel #3, 1" Free Run										
522	400 Series BALL	650	-	-	-	-	650	24,400	2291	-
523	" " "	650	-	-	-	-	650	25,000	-	3.27
524	" " "	650	-	-	-	-	650	24,100	2307	3.39
525	WC 760	650	-	-	-	-	650	32,500	-	3.00
526	"	650	-	-	-	-	650	35,600	2409	2.87
527	"	650	-	-	-	-	650	34,100	2392	2.95
528	WC 844	300	WC 680 Washed	Dipped B66	1.9%	404.0	700	41,600	2611	2.83

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets		Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
529	"	300	"	"	"	"	403.2	700	39,500	2573	3.11
530	"	300	"	"	"	"	404.2	700	40,200	2603	2.96
Barrel #3, 2" Free Run											
531	400 Series BALL	650		-	-	-	-	650	25,600	2351	3.15
532	" " "	650		-	-	-	-	650	25,400	2338	3.07
533	" " "	650		-	-	-	-	650	21,600	2278	3.43
534	WC 844	300	WC 844		Dipped NC, B66		475.0	775	34,300	2505	-
535	"	300	"		"		475.0	775	43,300	2554	-
Temperature Test, Barrel #3, 2" Free Run											
77°F.											
536	WC 844 2/3 Series B 1/3	250	WC 680		Dipped	1.9%	475.0	725	38,400	2621	2.78
537	" " "	250	"		"	"	475.0	725	37,500	2605	2.83
538	" " "	250	"		"	"	475.0	725	36,100	-	2.93
539	" " "	250	"		"	"	475.0	725	29,300	2477	3.38
540	" " "	250	"		"	"	475.0	725	38,600	2626	-
541	" " "	250	"		"	"	475.0	725	35,100	2561	3.12
542	" " "	250	"		"	"	475.0	725	23,600	2385	3.75
543	" " "	250	"		"	"	475.0	725	36,000	2593	2.87
544	" " "	250	"		"	"	475.0	725	17,900	2267	4.21
545	" " "	250	"		"	"	475.0	725	35,200	2594	2.75
+165°F.											
546	WC 844 2/3 Series B 1/3	250	WC 680		Dipped	1.9%	475.0	725	33,200	2557	2.99
547	" " "	250	"		"	"	475.0	725	29,900	2512	-
548	" " "	250	"		"	"	475.0	725	31,200	2676	2.89
549	" " "	250	"		"	"	475.0	725	34,600	2580	3.08
550	" " "	250	"		"	"	475.0	725	33,800	2558	2.76

-65°F.

Barrel #1

Shot No.	Granular Powder	Chg. Wt.	Pellets	Coating Type	Coating Amt.	Chg. Wt.	Total Chg. Wt. Nominal	Pressure psi	Velocity fps	A. T. ms
551	2/3 WC 844 1/3 400 Series B	250	WC 680	Dipped	1.9%	475.0	725	3,000	1106	8.80
552	" " "	250	"	"	"	475.0	725	24,600	2402	3.30
553	" " "	250	"	"	"	475.0	725	16,300	2166	3.89
554	" " "	250	"	"	"	475.0	725	5,400	1513	6.85
555	" " "	250	"	"	"	475.0	725	-	-	-
77°F.										
556	2/3 WC 844 1/3 400 Series B	300	WC 680	Dipped	1.9%	475.0	775	41,700	2731	-
557	" " "	300	"	"	"	475.0	775	51,200	2861	2.60
558	" " "	300	"	"	"	475.0	775	50,200	2824	2.63
559	" " "	300	"	"	"	475.0	775	52,300	2850	2.51
560	" " "	300	"	"	"	475.0	775	45,300	-	2.80
561	" " "	300	"	"	"	475.0	775	47,900	-	2.75
562	" " "	300	"	"	"	475.0	775	46,400	2808	2.72
563	" " "	300	"	"	"	475.0	775	49,400	2833	2.66
564	" " "	300	"	"	"	475.0	775	44,100	2771	2.84
565	" " "	300	"	"	"	475.0	775	42,700	2752	2.90
+165°F.										
566	2/3 WC 844 1/3 400 Series B	300	WC 680	Dipped	1.9%	475.0	775	45,700	2791	2.71
567	" " "	300	"	"	"	475.0	775	51,400	2846	2.62
568	" " "	300	"	"	"	475.0	775	48,100	2806	2.82
569	" " "	300	"	"	"	475.0	775	45,100	2789	2.72
570	" " "	300	"	"	"	475.0	775	43,600	2796	2.75
-65°F.										
571	2/3 WC 844 1/3 400 Series B	300	WC 680	Dipped	1.9%	475.0	775	21,700	2427	3.51
572	" " "	300	"	"	"	475.0	775	16,400	2258	4.08
573	" " "	300	"	"	"	475.0	775	30,800	2575	3.21
574	" " "	300	"	"	"	475.0	775	15,600	2229	4.08
575	" " "	300	"	"	"	475.0	775	10,300	1955	5.06

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